ADDRESSING STUDENTS' MISUNDERSTANDING OF BASIC CONCEPTS IN GENETICS THROUGH THE DEVELOPMENT OF TARGETED EDUCATIONAL RESOURCES

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Abstract

Misunderstanding of fundamental concepts is believed to be a major factor obstructing students from having a complete understanding of genetics. Similar misconceptions for the same basic concepts of genetics have been reported worldwide, and across all levels of education. This study combined information on the most common misconceptions in genetics in order to develop educational resources specifically designed to challenge university students' misunderstanding of the key concepts. Three targeted educational resources were developed on the topics of meiosis, Mendelian inheritance, and the concept of the gene. The resources were designed using three different formats: video, card activity, and information booklet, respectively. The choice of media format was determined by the particular common misconceptions targeted. The resource development was conducted in a four-stage action research approach of design, create, evaluate and reflect, a modification of the traditional four-stage approach of action research. The effectiveness of the resources in challenging students' misconceptions was evaluated based on any subsequent students' concept changes, how these resources had influenced these changes, and the students' learning experiences. Two university student cohorts took part in this study, Biology Education students from Universitas Tanjungpura in Indonesia and Biology and Biomedical undergraduate students from the University of Leicester in the United Kingdom. Research data were collected by means of tests, observation and interview and were analysed and triangulated using qualitative approaches. The study showed that all three educational resources effectively promoted changes to students' misconceptions. The effectiveness of the resources was dependent on their content presentation that challenged students' misconceptions. The engagement of both Indonesian and UK students was based on their perceived benefit of the resources rather than their enjoyment of the activity. This study also showed that it is possible to use a modified action research approach informed by published common misconceptions to create effective educational resources.

To my supervisors: Annette, Chris, Mark, Sarah and Cas

who taught me passion, compassion and how not to give up …

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I know that this is not a perfect thesis, but I do hope that this is a special one, as it will always be for me.

List of Content

List of Tables

List of Figures

List of abbreviations

DNA – Deoxyribose Nucleic Acid

GCA – Genetics Concept Assessment (Smith *et al*., 2008)

GCI – Genetics Concept Inventory (Elrod, 2007)

GLAI – Genetics Literacy Assessment Instrument (Bowling *et al*, 2008)

MCI - Meiosis Concept Inventory Test (Kalas *et al*., 2008)

MCIA – Most common incorrect answer (in Smith *et al*., 2008)

Chapter 1 - Introduction

Overview

This chapter sets out the rationale and scope of the research. The main themes of this research are common misconceptions, resource development, and conceptual change. The theoretical framework for conducting the research is explained. The four research questions, which correspond to a brief description of how this research will approach the problems, are presented in this chapter. The discussion of the significance of this study will give an insight into the importance of conducting the research. The chapter concludes with definitions of important terms that are used throughout this study.

1.1. Background of study

Genetics deals with the study of biologically inherited traits (Hartl and Jones, 2005; King, Mulligan, and Stansfield, 2013; Klug, Cummings, Spencer, and Palladino, 2016) transmitted by genes, which are units of heredity (Brown, 2012; Witherly, Perry, and Leja, 2001). Genetics is the core subject of biology (Raven and Johnson, 2002), because every subject in biology is related to the gene. Thus, genetics connects different topics across the subjects of biology into one integrated understanding. For example, understanding protein structure and function, which is crucial for studying biochemistry, is supported by an understanding of how a gene is expressed, and how the phenotype and physiology of an organism are related to its gene structure.

The significant advances in genetics research in recent decades have had a large impact on society (Lanie *et al*, 2004), particularly in relation to health, the economy and public policy (Kolstø, 2001; Miller, 1998). For decades, the study of genetics has made substantial contributions to society by increasing production of staple foods, and cotton and wool clothing through improving programmes of breeding and cultivation (Griffiths and Mayer-Smith, 2000). The impact of genetics on society has increased profoundly since recombinant DNA technology has been used to produce cloned animals and genetically modified crops (Griffiths and Mayer-Smith, 2000). Furthermore, extensive research on the molecular basis of genetic diseases has improved people's lives by providing tools for genetic risk assessment (Kessler, Collier, and Halbert, 2007) and prenatal diagnosis (Klug *et al*, 2016). In order to actively participate in making decisions regarding the use of these new genetic tools and to gain the full benefit of the available services, the general public needs to understand the basic concepts of genetics and the related terminology (Lanie *et al*, 2004). However, studies have shown that most

people have relatively little understanding of the basic concepts of genetics (Human Genetics Commission, 2001; Lanie *et al*, 2004), most likely due to incorrect information distributed by the media (Bates, 2005) and movie (Muela and Abril, 2013), so that they struggle to distinguish facts from inaccurate information (Jennings, 2004).

A poor understanding of the basic concepts of genetics is found not only among the general public, but also at the undergraduate level, as revealed by many studies (e.g. (Andrews et al, 2012; Bowling et al, 2008; Kindfield, 1991; LeVaughn, 2016; Quinn, Pegg and Panizzon, 2009; Smith and Knight, 2013). In these studies, students' confusion regarding the key concepts of genetics was related to misconceptions arising from their basic introduction at secondary school. It was found that students in various parts of the world suffered from similar types of misconceptions regarding the basic concepts of genetics e.g. in Turkey (Tekkaya, Özkan and Sungur, 2001), Zambia (Haambokoma, 2007), Indonesia (Nusantari, 2011; Suparyana, 2014), Australia (Tsui and Treagust, 2007), Israel (Marbach-Ad, 2001), the United Kingdom (Lewis, Leach and Wood-Robinson, 2000b; Wood-Robinson, Lewis and Leach, 2000) and the United States (Mills Shaw, Van Horne, Zhang, and Boughman, 2008).

Misconceptions or misunderstandings are alternative or erroneous ideas that do not confirm the scientific convention (Bahar, 2003; Barrass, 1984; Elrod, 2008; Sawyer, 2005). Although pre-existing misconceptions were not the only factor that hindered students' learning, it is important to consider this factor, since students are constructing knowledge through their learning process and, with their limited understanding of certain basic topics, they may misinterpret and misunderstand the concepts (Clement, 1982). Misconceptions are often resistant to modification, particularly by conventional techniques, and their modification may require specific techniques, known as conceptual change strategies (Fisher and Moody, 2000; Wandersee, Mintzes and Novak, 1994), which enable students to confront their erroneous beliefs and eventually accept the introduced scientific ideas. Bringing about conceptual change requires extra effort from teachers, since they need to first identify the students' misconceptions and then apply strategies to overcome them. Identifying misconceptions in the classroom can be difficult, since they are often not expressed, and eliciting them from students may be time-consuming for teachers (Fisher and Moody, 2000).

The extensive literature on the findings of misconceptions of basic concepts of genetics across various ages and levels of education could provide a valuable resource for predicting students' misconceptions and could enable teachers to prepare in advance

strategies for combatting them. There are many learning resources available regarding the basic concepts of genetics, reviewed comprehensively by Haga (2006). However, creating teaching materials is one of the normal duties of teachers (Gagné et al., 2005; Kemp, 1977), and this could be one area where teachers might create their own teaching resources aimed at overcoming students' misconceptions. Action research is an approach in education in which teachers research the impact of their own actions and make appropriate improvements (Stringer, 2014; Cohen, Manion and Morrison, 2011).

The selection of topics of the basic concepts of genetics that were targeted in this study was based on a number of factors: the analysis of their coverage in the national syllabuses of secondary schools in Indonesia and the UK; the large amount of literature related to misconceptions of these topics, including the development of related conceptual testing e.g. Meiosis Concept Inventory (MCI) (D'Avanzo, 2008), Genetics Conceptual Assessment (GCA) (Smith, Wood, and Knight., 2008), the Genetics Concept Inventory (GCI) (Elrod, 2008), and the Genetics Literacy Assessment Instrument (GLAI) (Bowling *et al*, 2008); and the discussion of these topics in various undergraduate biology textbooks (Raven and Johnson, 2002; Reece *et al*, 2014) and genetics textbooks (Brown, 1992; Brown, 2012; Elrod, Susan and Stansfield, 2007; Hartl and Jones, 2005; Pierce, 2010). In addition, the importance of particular concepts for the development of an understanding of genetics was also taken into account.

Based on the considerations described above, three topics of genetics chosen for this study: the concept of a gene, Mendelian inheritance, and meiosis. A gene is a unit of inheritance and a core theme within genetics. The simplest mode of inheritance of a gene is through Mendelian or so-called single gene inheritance. Understanding the key principles of Mendelian inheritance, such as segregation and independent assortment, requires an understanding of how a gamete is produced from a specialised type of cell division called meiosis.

Problems in understanding basic concepts of genetics had been found among students in different programmes at two universities, in two different countries. Student teachers on the biology education programme at Universitas Tanjungpura in Indonesia (training to become secondary school biology teachers) require an excellent understanding of the basic concepts of genetics. However, these students had shown a low level of understanding of these concepts, due to misunderstandings originating from their schooling (Candramila, 2014). Perhaps unexpectedly, a similarly low level of

understanding had been found in undergraduate biological and biomedical sciences students at the University of Leicester in the United Kingdom (Cashmore, 2014).

Indonesia, a developing country, realises the importance of having future geneticists and has given particular attention to the problem of teaching and learning of genetics (as indicated by the State Minister of Research and Technology of Indonesia; Berita Kegiatan Ristek (2011)). On the other hand, the United Kingdom possesses advanced research in the genetics-related field, the low understanding of basic concepts in genetics among the public as well secondary school students is concerning (Lanie *et al*, 2004; Lewis, Leach and Wood-Robinson, 2000c). Therefore, the development and evaluation of educational resources involving two groups of students taking different programmes, in the two different countries, was the initial aim of this study.

1.2. Theoretical framework

The constructivist approach is the core method used in science education (Duit, 1999). This approach is based on the view that individuals construct knowledge through their experience, and that learning is an active process in which learners engage with and build new ideas or concepts based upon their current and past knowledge (Jaques & Salmon, 2007). This perspective holds that knowledge cannot be transmitted, but must be actively constructed by the learner (Kintsch, 2009). In the attempt to make sense of new information, students may form misinterpretations due to being misinformed, lacking visual acuity or obtaining ambiguous information (Newton, 2011). As mentioned before, a misconception is an incorrect interpretation of meaning, which differs from the common scientific view (Bahar, 2003; Elrod, 2007; Sawyer, 2005). Misconceptions are often shared by a large proportion of students in classrooms worldwide, therefore leading to the term ‘common misconceptions’, and they are resistant to change, particularly by didactic teaching methods (Fisher & Moody, 2000; Wandersee, Mintzes & Novak, 1994).

In 1936 Jean Piaget suggested two ways of constructing knowledge: the integration of new information into existing knowledge (assimilation), and the reorganisation of existing ideas (accommodation) (McLeod, 2015). The two terms were adapted by Posner, Strike, Hewson, and Gertzog (1982), who described conceptual change models, illustrating two ways by which new concepts may be incorporated into a learner’s understanding, i.e. integration with existing knowledge (assimilation), or replacement of existing knowledge (accommodation). A similar pattern of modification

of misconceptions was also proposed by Hewson (1982) and Vosniadou (1994). Conceptual change links to 'accommodation', where knowledge is constructed through four stages: considering newly introduced concepts as intelligible; realising the plausibility of applying the new concepts to explain phenomena; accepting the fruitfulness or value of new insights; and developing dissatisfaction with the old concepts and replacing them with the new ones (Strike and Posner, 1985). Thorley & Stofflet (1996) pointed out that the intelligibility, plausibility, and fruitfulness of new concepts could be demonstrated by using representation, including the use of linguistic expression, images, and metaphor and analogy. Concept visualisation using pictures, diagrams and tables forms another type of representation (Gilbert, Reiner, & Nakhleh, 2008).

An external representation is any symbol that exemplifies a concept by creating a mental model (Eysenck and Keane, 2000). The use of representations of concepts to address misconceptions (Ainsworth, 2006) could be integrated into teaching resources. Within the constructivist paradigm, the teacher's function in the classroom becomes that of a facilitator of students' learning rather than one of just simply passing the information to the students (Confrey, 1990). Thus, creating representations that challenge students' misconceptions and enhance their understanding of concepts is one way to meet the requirement of teaching in a constructivist paradigm. The effectiveness of teaching resources could be evaluated by assessing success in the achievement of their intended purposes, and the students' acceptance of those resources (Gagné *et al*, 2005; Gall, Borg, and Gall, 2003; Kemp, 1977).

1.3. Aims of study and research questions

This study aims to develop effective educational resources for selected topics in the basic concepts of genetics that are based on common misconceptions and assist conceptual change.

Four research questions were developed to achieve this:

1. How is information regarding common misconceptions used to develop the targeted educational resource?
2. What are university students' existing perceptions of the basic concepts of genetics?
3. In what ways do the targeted educational resources modify university students' misconceptions of basic concepts in genetics?

   3.1: What misconceptions are altered after use of the targeted resources?

3.2: What elements of the targeted resources contribute to the change?

3.3: How do university students perceive their learning experience with the targeted resources?

4. Are there any differences in the way university students in Indonesia and the United Kingdom perceive the benefits of the targeted educational resources?

1.4. Research approach

This study was conducted using the action research approach. In order to develop targeted educational resources the four-step cycle of 'plan > act > observe > reflect' of Lewin's model of action research (Costello, 2011; Cohen *et al.*, 2011) was used and adapted to a four-step cycle of 'design > create > evaluate > reflect'. Multiple data sources (development journal, testing, observation, and interview) were triangulated and analysed qualitatively in addressing the research questions, according to (Merriam, 2009). Evaluation of the resources involved two groups of university students taking a genetics module in their study programme: biology education student teachers at Universitas Tanjungpura in Indonesia, and biology and biomedical undergraduate students at the University of Leicester in the United Kingdom. Further details of the research methodology will be presented in Chapter 3.

1.5. Significance of study

The significance of this research concerns the production of effective educational resources aimed at combatting students' misconceptions of some of the basic concepts of genetics. An assessment of the effectiveness of developing resources for the classroom context using an action research approach based on common worldwide misconceptions, will give an insight into the value and limitations of adopting the same mechanism to develop other resources for different topics within genetics, and for science subjects in general.

1.6. Important terminologies

This section provides a glossary of terminologies related to concepts discussed in this study and are used widely in various chapters of this thesis. The terms are presented alphabetically.

Basic concepts of genetics: topics in genetics that are perceived as important and are considered to be the foundations for the understanding of other concepts, signified

by their coverage in the national syllabuses of secondary schools, and the common university biology and genetics textbooks. The terms *core, fundamental,* or *key ideas* also refer to this definition.

Common misconceptions: misconceptions/misunderstandings of specific topics (of genetics) found in common in classrooms worldwide, across various levels of education (Fisher & Moody, 2000).

Conceptual change model: a model for modifying misconceptions initially proposed by Posner *et al* (1982) and later revised by Strike and Posner (1985) and reviewed by Thorley & Stofflet (1996). The conceptual change model consists of four conditions: intelligibility, plausibility, fruitfulness, and dissatisfaction with former conceptions (IPFD).

Representations: various types of external representations in biology including analogies, metaphors, visualisation (e.g. diagrams, pictures, and tables), discourse, models and model-based learning, and multilevel representations (Tsui and Treagust, 2013).

Targeted educational resources: teaching/learning resources that are created based on a constructivist view, which considers the need to facilitate students' active construction of an understanding of the content (Confrey, 1990). The target of these resources is to challenge students' misconceptions, and they can be presented in different media format. The terms *teaching resources/tools* or *learning resources/tools* also refer to this definition.

Chapter 2 – Literature Review

Overview

This chapter is intended to provide readers with structure of theories relating to this study. The review of literature begins with a search for plausible definitions of the concept and of conceptions, which in turn serve as a basis for defining the conceptual understanding explored in this study. The aspects of conceptual change and related elements are discussed in the next part, which serves as a tool for measuring conceptual understanding. In the other parts of this chapter, a deeper discussion takes place on determining what are considered the basic concepts of genetics, with a framework for developing resources. This chapter concludes with a section on the importance of analogy as a basis for developing resources.

2.1. Learning as constructing knowledge

Constructivism is a philosophical view that considers human knowledge as a construction of understanding. It revolutionizes the initial concept of seeing knowledge as a representation of reality. Constructivism is a humble claim that human knowledge consists simply by human construction of understanding. The justification for the meaning of knowledge is very pragmatic, that is as long as the knowledge is useful in reaching the practical goal (Colliver, 2002). The theory was then adapted for the educational field. The idea that "knowledge is constructed in the mind of learner" (Bodner, 1986, p.873) soon replaced the general accepted view of transmittable knowledge (Kintsch, 2009), and the core for instruction in science education (Duit, 1999; Matthews, 2002). Although constructivism was differentiated later into several specified types, among the most popular are cognitive, critical, radical, and social constructivism, however, they have the same fundamental idea of learners constructing their own knowledge (Sener, 1997) through actively making meaning of the phenomena they experience (Jaques and Salmon, 2007). However, due to the subjective individual construction of knowledge, there is no standard of what is valued as knowledge. For the constructivist, everyone ideas are just as valid (Poerksen, 2004) and leading to the concept of multiple realities (Driscoll, 1994).

Constructivist pedagogies are signified by four attributes: learners construct their own meaning, learning is dependent on existing understandings, authentic learning tasks are crucial for meaningful learning, and social interaction plays a key role in the meaning making (Brunning, *et al*., 1995). Because constructing knowledge may lead to multiple realities, students may have different ideas as to what is accepted as scientific

convention, which are categorised as misunderstandings or misconceptions (Bahar, 2003; Newton, 2011). Constructivism mostly related to the work of Piaget, particularly to his proposed explanation of constructing knowledge acquisition, the assimilation (integrating of new knowledge into the existing conception) and the accommodation (replacing the existing conceptions with the new ideas) (McLeod, 2015) later inspired the proposition of modifying misconception through conceptual change model (Posner *et al*, 1982).

Despite the wide acceptance of constructivism, some authors highlight the misleading conception some instructors have that constructivist pedagogy is merely creating an activity which allows students to have active behaviours, but this approach does not help them actively constructing knowledge (Boghossian, 2017; Hyslop-Margison and Strobel, 2008). Therefore, the design and development of a task should be directed to the facilitation of learning, not simply something which requires active behaviour.

2.2. Concept and conception

Several experts have variously defined a concept. Philosophically, Thagard (1992) views concepts either as theoretical entities (non-natural, mental, linguistic or abstracted) or non-entities (fictions or emergent states). All concepts refer to one of 10 possible functions, i.e. categorisation, learning, memory, deductive inference, explanation, problem solving, generalisation, analogical inference, language comprehension, and language production, as put by Thagard. White (1994) also referred to a concept as a certain classification of an object. However, accordingly, he also connected a concept definition to "all knowledge that a person has, and associate with the concepts' name" (p.118). The idea of defining a concept is slightly different for Schwedes and Schmidt, (1992), who perceive a concept as not merely a single idea, but as an aggregate of many connected ideas in explaining some sort of problem or situation. Novak, (1978) offered a more thorough definition of a concept by defined it as a name for a structured event, which could combine in making a proposition without losing its hierarchy. Ferrari and Elik, (2003) highlighted how a concept also had a social dimension by having the characteristic that it could be discussed within society. In summary, all expert definitions of concept take the view of a concept as an object or event which can be categorised or named to differentiate it from other events.

Conception is different from a concept, in terms of it first marking the complexity of the object (Posner *et al*, 1982). Duit and Glynn, (1996) perceived conception as the mental model inside a learner's mind. Functionally, conception has the power to give causal explanation, and make a prediction of certain phenomena (Vosniadou, 1994). The definition of representation may be well provided by Hiebert and Carpenter, (1992), who defined it as the way of communicating ideas, either by thinking them internally, or by communicating with others through speaking, writing, drawing or mediating through a combination of all mentioned forms.

2.3. Common misconceptions

Misconceptions are incorrect understandings to the phenomena in science. Misconceptions are due to misinterpretation of meaning when learners attempt to construct their knowledge and indicated by their differences from the current scientific convention (Bahar, 2003; Elrod, 2007; Sawyer, 2005). Modifying misconceptions is important in learning since the- misconceptions- will integrate into the existing knowledge of an individual which will hinder the individual in obtaining conceptual understanding (Clement, 1982; Brunning, *et al*., 1995).

Misconceptions are characterised by the resistance to change in conventional instruction., In conventional instruction, students did not have much opportunity to experience cognitive conflict to revise their incorrect conceptions (Wandersee *et al.*, 1994) The construction of knowledge is subjective and therefore can lead to multiple realities (Driscoll, 1994) which become individual misconceptions. Teachers/instructors need to identify theses individual misconceptions of students in their classrooms before applying the strategies to overcome them. According to Fisher and Moody (2000), identifying misconceptions in the classroom could be problematic due to three factors. Firstly, misconceptions are very subtle and hard for a teacher to identify, therefore, it may be several years before students become aware that they have a different conception from the scientific convention. Secondly, they may persist even amongst the brightest students in the classroom. A study by Mills Shaw *et al*, (2008) confirmed this, revealing that more than 50% of the students who participated in writing essays for the US National DNA Day contest revealed at least one misconception about genetics in their essay. The participating students represented their schools as the best students in particular subjects, so misconceptions may persist even among high-achievers. And thirdly, identifying individual misconception in the classroom can be time consuming.

Therefore, the large literature on misconceptions of topics of interest is a valuable source in to predicting types of individual students' misconceptions in a classroom and prepare the strategies for confronting these before coming to the classroom.

The common misconceptions that students have in the classroom could also be identified by using specific testing tools called Concept Inventories (CI). The use of CIs as a means of enhancing teaching and learning process was initially demonstrated in Physics through the development and use of the Force Concept Inventory (FCI) (Garvin-Doxas, Klymkowsky and Elrod, 2007). The FCI is a multiple-choice test originally developed by Hestenes et al., in 1992 designed to measure students' concept understanding of force and kinematics concepts. Students are assumed to understand conceptually if they can identify correct answer from a range of answer options that also includes common misconceptions. Due to its validity in measuring students' concept understanding (Hestenes and Halloun, 1995), the FCI became a popular tool to evaluate the effectiveness of specific instruction developed in teaching force and kinematics concepts in physics (Savinainen and Virii, 2007; Garvin-Doxas and Klymkowsky, 2008).

The success of the development of FCI in physics had inspired scientists in other areas to develop similar evaluation tools for their subject. In chemistry, the Chemistry Concept Inventory (CCI) was initially introduced by Mulford and Robinsons in 2002. Pavelich et al., (2004) developed different set of questions for the topics which were not covered by the first CC. However, they still adopted the same term "CCI" for this test since it has the same purpose of is built by based on identified students' misconceptions in Introductory Chemistry. Meanwhile in Biology, instructors from various universities had tried to develop various Concept Inventories focused on different subjects within Biology (Garvin-Doxas, *et al*., 2007). Among those Concept Inventories are Genetics Concept Inventory (GCI) and Meiosis Concept Inventory (MCI) (D'Avanzo, 2008).

There are also other assessment tools which share similar purpose as CI, e.g. Genetics Conceptual Assessment (GCA) (Smith *et al*, 2008), and the Genetics Literacy Assessment Instrument (GLAI) (Bowling *et al*, 2008). The latter two differ from CI only in the context of they are developed identifying difficult concept in genetics. Although the difficult concepts did not always occur as misconceptions, these learning assessment tools are valuable resources for focusing on basic genetics, where new resources need to be developed.

Misconception is the term that correspond to the incorrect interpretation and meaning in which they are different from the common scientific view (Bahar, 2003). Misconceptions are characterised by the fact that they are shared by a large proportion of students in classrooms worldwide (as the origin of the term common misconceptions) and they are resistant to change especially with didactic teaching methods (Fisher and Moody, 2000).

2.4. Conceptual change

In being assured that a conceptual change has happened, we need to establish what is conceptual change (ontological perspective), and how we know that it has happened (epistemological justification).

Conceptual change is rooted in constructivist approaches to learning. Having a change in the conception of science during the learning process is like changing one's conception of science through understanding the findings of scientific research. Thus, this is known as a theory of children learning like scientists (Posner *et al*, 1982). Changes take place using two stages, "assimilation", and "accommodation". Assimilation means that students preserve their existing conceptions and use them to learn new concepts accordingly, while in accommodation, students replace/reorganise their existing conceptions because they cannot reconcile the new conceptions. Using different terms, but a similar meaning, Hewson (1982) put forward the idea of "conceptual capture" and "conceptual exchange" (p.76). However, some experts argue that assuming conceptual change in a student as scientist is not appropriate, since it does not account for the fundamental factor of a learner's intention in making changes happen. In short, to let conceptual change take place, there should be an intentional element, both motivational (internal) and situational (social) (Pintrich, Marx and Boyle, 1993). Apart from that, Chi, Slotta and De Leeuw (1994) propose three ontological categories: matter, processes, and mental states. Conceptual changes may take place within each category; however, it is more difficult for them to occur across categories which would involve radical conceptual changes. The latter situation happens when students have different categorical representations for a concept.

In addressing the epistemological issue in regard to conceptual change, the conceptual change model (CCM) of (Posner *et al*, 1982) serves as a basis for interpreting students' conceptual learning. Based on CCM, (Hewson and Hennessey, 1992) put forward the four conditions under which students may change their

conception. First, they must be dissatisfied with their existing knowledge, which can no longer serve as a good explanation for the problem or phenomenon they are dealing with. Second, they can understand (intelligibility) the new conceptions. Third, they find the new conceptions plausible in giving them a good reason to solve the problem. Lastly, they may produce a good result, or in this case solve the problem, by using the new conceptions. Accordingly, Thorley (1990) as cited in Tsui (2003) constructed a status analysis for interpreting the status of students' conceptions in terms of the second of the four conditions: accordingly, I (intelligibility), IP (Intelligibility-Plausible), or IPF (Intelligibility-Plausible-Fruitfulness). The summary is presented in Table 2.1.

Table 2. 1 Tsui's categories for analysing conceptual status adapted from Hewson and Lemberger (2000) and Thorley (1990) (Tsui, 2003)

Status of conceptions	**Status Elements**
INTELLIGIBILITY	INTELLIGIBILITY ANALOGY (analogy or metaphor to represent conceptions) IMAGE (use of pictures or diagrams to represent conceptions) EXEMPLAR (real-world exemplar of conceptions) LANGUAGE (linguistic or symbolic representation of conceptions)
PLAUSIBILITY	Consistency factors: OTHER KNOWLEDGE (reasoned consistency with other high-status knowledge)
	LAB EXPERIENCE (consistency with laboratory data or observation)
	PAST EXPERIENCE (particular events consistent with conception)
	EPISTEMOLOGY (consistency with epistemological commitments)
	METAPHYSICS (reference to ontological status of objects or beliefs)
	PLAUSIBILITY ANALOGY or P ANALOGY (another conception is invoked)
	Other factors: REAL MECHANISM (causal mechanism invoked)
FRUITFULNES	POWER (conception has wide applicability)
	PROMISE (looking forward to what new conception might do)
	COMPETE (explicitly comparing two competing conceptions)
	EXTRINSIC (associating new conceptions with experts)

In discussing factors contributing to conceptual change, Vosniadou (1994) argued two major procedures: the enrichment (addition) and the revision. Between those two,

the latter is the more difficult to execute, since it involves correcting the foundation of the knowledge base. Although conceptual change is important in learning, this event does not occur easily in daily learning activities. One reason for that is because students often hold preconceptions which come from their daily experience, and there is no challenge to the associated conception. If their preconceptions have been challenged (dissatisfied), it does not mean that conceptual change would happen automatically. Although they may understand the new conceptions (intelligibility), they do not believe in them (have no plausibility), so conceptual change would not take place (Duit, 1999). Chinn and Brewer, 1993) considered that the most important factors that obstruct conceptual change are well-established beliefs. The changes may occur only if they are confronted with "very convincing anomalous data" (p.15). The latter has become the fundamental thing to consider in developing resources.

In creating a conceptual change, students need to believe that the new conceptions can offer coherent explanations (Thagard, 1992). However, although when students follow this approach, a follow-up problem still exists. First, they may fail in organising new concepts within their knowledge, so that their notions lack the experts' systematicity and coherence (diSessa, 1993). Second, the informal naïve conceptions (misconceptions) that students bring to lessons can co-exist with the formal scientific conceptions they learn in the classroom (Driver, Asoko, Leach, Scott, and Mortimer, 1994). These problems will be considered in evaluating conceptual change using resources.

2.5. Role of interest and motivation in conceptual changes

In terms of external representation, analogies serve as powerful learning strategies for promoting conceptual understanding. Analogy simplifies complicated contents, motivating students to learn by increasing their self-efficacy (Venville and Treagust, 1996). However, the use of analogy in the classroom needs to be considered carefully. Although it may facilitate comprehension and problem-solving, it may also lead to misunderstandings and eventually generate alternative conceptions (Glynn, 1991; Treagust, 1997). However, analogies help motivate students to learn. Using analogies may help students relate abstract concepts to the real world by promoting visualisation of invisible abstract phenomena. Visualisation is intrinsically motivating and can facilitate conceptual understanding through making connections between concepts (Treagust, Duit, Joslin, and Lindauer, 1992). The use of visual representation in natural

science is pervasive, as shown in high school textbooks (LaDue, Libarkin, and Thomas, 2016). In analysing visualisation, Rau (2017, 2018) emphasised that in dealing with visualisations which involve multiple representations (e.g. representation of oxygen presented using various model and approach), firstly students need to understand the content (of the representation and link that knowledge to their existing understanding and secondly, they need additional time to translate the understanding from the first representation to other representations. This situation creates the concept referred to as "representational dilemma" which should be considered as it hinders students in conceptually learning from the given representations.

Many experts have discussed the motivational aspect of conceptual change. Motivation plays an important role in changing concepts held by students. It can be either extrinsic (e.g. reward for activity) or intrinsic (e.g. interest in activity). Malone and Lepper (1987) developed a taxonomy of personal intrinsic motivations: curiosity, control, challenge, and fantasy; and of extrinsic motivations: cooperation, competition, and recognition. Intrinsic motivation may arise from individual interests which represent personality-specific orientations, reference valuations, or awareness of possibilities for actions. Extrinsic motivation, on the other hand, may come from situational interests; it refers to the interest that is "generated primarily by certain conditions and/or concrete objects (e.g. texts, film) in the environment" (Krapp, Hidi and Renninger, 1992). Within social constructivist approaches, particularly those related to Vygotsky's notion of the zone of proximal development, Carter, Westbrook and Thompkins (1999) argue that the tool for introducing new conceptions should be inside the students' zone of proximal development. Students could not use these tools to develop their understanding of a concept which contributes later to them failing to make a conceptual change.

2.6. Factors to consider in developing new resources

Developing a new resource within an instructional design forms part of a programme of instruction. Instruction is defined as "a set of events embedded in purposeful activities that facilitate learning" (Gagné *et al.*, 2005). When a resource is designed, the learning process becomes the focus of study. One of the ultimate goals of learning is developing intellectual skills, which consist of declarative and procedural knowledge. The first knowledge facilitates students in differentiating characteristics of certain concepts to one another.

However, Newton, (2011) argued that learning to get knowledge is not sufficient. The focus of learning should be directed at earning procedural and conceptual understanding, rather than merely gaining knowledge. Newton claimed that "*acquiring understanding would help students to relate their current knowledge to new concepts, and to apply the concepts within the new context. Understanding also promotes knowledge retention and enables critical thinking abilities*" (p.10). The importance of promoting conceptual and procedural understanding is also highlighted by the theory of "Learning Science" (Sawyer, 2005).

Learning science is a scientific approach which has been developed to understand how the learning process takes place. This approach considers learning as a medium that facilitates deeper conceptual understanding. This kind of understanding is achieved through grasping complex concepts, facts and procedures. Learning scientists argue that their view of learning is opposite to the traditional views of learning. Their view which is named instructionism, considers learning to be a process of transmitting knowledge. In this case, learning science takes a constructivism perspective in which learning takes place when learners actively construct knowledge in order to achieve the goal of learning, to move from the novice (learner) to expert status (Sawyer, 2005).

Learning science also suggests the use of visualisation as a medium to help students to learn. "Constructionism" is the term used in instructional design based on constructivism. Learning facilitation emerges in the "object-to-think-with" form to help students to construct and revisit (reflect) their learning process. Although this principle has become a foundation for education technology to develop digital objects as learning scaffolding, the original idea was to develop either physical or digital objects (Kafai, 2005). Since objects are developed to facilitate students in assimilating or accommodating their knowledge, this process eventually leads to conceptual change. According to (diSessa, 2005), understanding the type of conceptual change is also important. Mostly the mechanism for conceptual change can be explained as a shifting of knowledge which corresponds to scientists' conceptual change along the path of scientific history. She used this to criticise the approach in which many researchers have assumed that conceptual change could be tracked using pre- and post-test techniques, which may not be sufficient to reveal conceptual change. Although this suggestion may look practical, she proposed more appropriate and accurate techniques to reveal conceptual change. Interview techniques were found in studies conducted by Venville and his colleagues (Venville, Grady, Gribble and Donovan, 2005; Venville, Grady and

Donovan, 2007) to be more appropriate. This is because an interview can generate rich qualitative data, while a simple test is a more reductionist quantitative (Gillham, 2005). Therefore, interviews can give more comprehensive analysis of the processes of conceptual change.

The role of genetics in society has been acknowledged, with Griffiths and Mayer-Smith (2000) highlighting some of the remarkable contributions among its many applications. In the medical sector, intensive research in genetics has provided a protocol to identify inherited diseases and offers an understanding of how various diseases arise due to "faulty" genes. Genetics has also played an important role in the agricultural sector, as genetic engineering allows geneticists to produce fortified cultivars and overcome plant diseases. Another notable contribution of genetics to society is the invention of the DNA fingerprinting technique as the unique personal identification of each citizen (Jeffreys, 1993). Because of the daily application of genetics in society, Mills Shaw *et al*, (2008) suggested that acquiring at least the basic principles of genetics was important. However, studies have uncovered poor public understanding of basic genetics concepts (Lanie *et al*, 2004; Shaw and Hurst, 2008). In both studies, the authors used the term "genetics literacy" to describe levels of understanding. A more recent study further revealed that low understanding of basic concepts of genetics among well-educated professionals in three countries, Russia, the UK, and the USA (Chapman, Likhanov, Selita, Zakharov, Smith-Woolley and Kovas, 2017).

The term genetics literacy does not apply only to public understanding, but also to students in their formal education. Students aged 14-16 in the United Kingdom have "a very limited understanding of the most basic concept of genetics" covering the nature of genes, the relationship between genes, chromosomes and inheritance, and genetic material within cells (Lewis, Leach and Wood-Robinson, 2000a; Lewis, Leach and Wood-Robinson, 2000b; Lewis and Wood-Robinson, 2000; Lewis, Leach and Wood-Robinson, 2000c; Wood-Robinson, Lewis and Leach, 2000). Similar research conducted in Israel confirmed a limited understanding of basic concepts in genetics (Marbach-Ad, 2001; Marbach-Ad and Stavy, 2000). Poor understanding of genetics concepts was not restricted to middle school but included post-16 and higher education. Studies conducted among high school students (college form education) showed a similar situation (Tekkaya, Özkan and Sungur, 2001; Haambokoma, 2007) and this was also observed at university level (Chattopadhyay, 2005). The same situation was found

in intensive genetics research in the United States (Smith and Knight, 2012; Kindfield, 1994).

Several notable factors have been linked to difficulties in learning genetics. A study conducted by Chu and Reid, (2012) showed that difficulties in learning genetics persist as students are exposed to learn various new concepts in a short period of time. This may happen because students experienced poor understanding of these concepts in their previous studies. Instead of learning in a series of continuum steps, students with poor understanding will try to force themselves to understand all concepts in one period of learning. Their failure in learning was related to the condition referred to "overloading working memory" (Eysenck & Keane, 2000). Working memory is a concept in cognitive psychology used to explain the temporary capacity of the brain to hold new information. This capacity would be greater if the foundational concepts have already been acquired, so that students need only link the latest information with their acquired concepts. Difficulties occur if students try to learn all the information at the same time (Newton, 2011). Research in this field suggests that concepts in genetics need to be delivered systematically, ensuring students understand concepts at each level of education.

To structure concepts in genetics instruction, various approaches to the curriculum may be applied. Griffiths and Mayer-Smith (2000) listed five different approaches commonly used in teaching genetics. These are based on what concepts instructors employ to introduce genetics concepts, either Mendelian, DNA, mutation, simple organism, or human genetics. The "Mendelian first approach" – more popularly known as the "historical approach" – was commonly used. In following this approach, students are presented with genetics concepts along a timeline of discovery. Classical Mendelian inheritance is often used as the primary focus in genetics instruction. Although this approach was popular among genetics instructors, (Dougherty, 2010; McElhinny, Dougherty, Bowling, and Libarkin, 2014) argued that problems in understanding genetics content persist because of this outdated curriculum approach. The "historical approach" or, as they referred to it, "traditional genetics instruction", would focus students on classical Mendelian patterns of inheritance. Therefore, every time students are exposed to concepts that do not fit this pattern, they will find it difficult to learn the new concept. Instead they try to modify the new concept to perfectly fit Mendelian inheritance. An example of this is the concept of polygenic traits. Students tend to think that all traits are inherited using a monogenic plan, while only a limited number of traits

in humans show that pattern of inheritance. To change this view, it was suggested teachers use the "inverted approach", in which students would be exposed to the inheritance of various traits and eventually learns the mechanism of Mendelian genetics.

Another contributor to the organisation of teaching genetics concepts is Corebima, 2002), who suggests the use of a "conceptual approach". Using this approach, the genetics curriculum is built around the central theme of the gene. Classical Mendelian genetics is taught at the same time as a molecular approach when discussing gene transmission concepts. The gap between classical Mendelian inheritance and molecular inheritance can be blurred, thus helping students to understand the bigger picture in genetics. A variation on this focus on the gene as the central theme in learning genetics has been suggested by (Smith and Adkison, 2010). They used the advancing definition of genes within the timeline of genetics research, with a mapping technique to show the advancing path of gene definition. The integration between concepts becomes a good framework in developing new resources.

2.7. Three selected topics of basic concepts of genetics

The (Cambridge dictionary[a], 2019) defines fundamental as "*of or serving as a foundation or core; of central importance*". Thus, the fundamental concepts in genetics could be seen as the crucial idea which became the basis for understanding the whole-body knowledge of genetics. In other words, all related concepts in genetics would be linked to one or more of these foundational ideas.

The way we determine fundamental concepts is directed by the paradigm we use to understand how entire topics in a subject are related. (Griffiths and Mayer-Smith, 2000) explained major approaches to understanding genetics as a subject, with the historical approach as the most popular. Since genetics is understood by learning each episode of discovery and invention of its concepts by geneticists, understanding the principles of Mendelian inheritance becomes a critical point. On the other hand, (Brown, 1992; Dougherty, 2010; Dougherty, Pleasants, Solow, Wong, and Zhang, 2011) offered the molecular approach to understanding genetics, in which the molecular aspects of inheritance (e.g. the structure of DNA/RNA, gene expression) become the key factors in learning the subject. This approach puts the gene at the centre of discussion in genetics.

Corebima (2002) adopted his approach to bring out seven themes (with genes at the centre) in learning genetics, i.e. structure of gene, gene reproduction, gene

transmission, gene expression and regulation, the gene alteration, gene in population, and modifying genes with genetic engineering. He used what he called the conceptual approach to explain each theme. The conceptual approach as he conceives it is identified with using any concept in genetics – whatever the period of discovery – necessary to explain a certain phenomenon. For example, rather than covering the concept of DNA replication and cell division as it developed at different times, he suggested putting them together to discuss how genes of interest are multiplied in the individual. The latter approach provides a more comprehensive way to consider the fundamental concepts.

The fundamental concepts of genetics relate closely to concepts in genetics literacy. Jennings (2004) elucidated the meaning of genetics literacy as the ability to understand information related to genetics which inform an individual to act or respond accordingly. Being literate in genetics information means that an individual would understand the meaning of the information which relates to his/her own life. He also suggested that genetics literacy in the near future should cover more than just the basic concept as it was at the time he was writing. He concluded that technical terms such as "*proteomics and haplotype mapping*" (p.8) would at some time be in public use. However, with the same idea, Lanie *et al*, (2004) focused more on studying public understanding of basic concepts which related to patterns of inheritance.

Basic concepts of genetics could also be determined by looking at the selected concepts taught in secondary school. In formal education, fundamental concepts of genetics are ideally introduced in the middle (secondary) school, although Venville, Grady and Donovan (2007) showed that primary school students were able to grasp the initial idea of a gene. Certain concepts were seen to be generating many misconceptions and became the focus of attention of researchers; some of these were later developed into concept inventories or similar tests, giving information on both basic and difficult concepts in genetics. The main examples are the meiosis inventory test (Kalas, O'Neill, Pollock, and Birol, 2013), genetics concept assessment (Smith *et al.*, 2008), genetics literacy assessment instrument (Bowling *et al*, 2008). Other investigations of concepts difficult for undergraduates (Clark and Mathis, 2000; Kindfield, 1994; McElhinny *et al*, 2014), or for high school students (e.g. Freire, Xavier, and Moraes, (2012); Mills Shaw *et al*, (2008); Stewart, (1982)) and middle school students (e.g. Lewis, Leach and Wood-Robinson, 2000a; Wood-Robinson, Lewis and Leach, 2000) acted as sources to

identify the fundamental concepts in genetics, as well as to locate the common misconceptions regarding those particular concepts.

The basic concepts in genetics and the common misconceptions attaching to those ideas are summarised in Table 2.2. All the concepts were categorised using Corebima's lens of conceptual approaches in genetics, comprising seven topics. The common attributed misconceptions are gathered through analysing related literature reviews mentioned in the previous paragraph.

2.7.1. Meiosis at a glance

Meiosis is one the most vital concepts in biology. Understanding meiosis becomes crucial in learning not only genetics, but other major sub disciplines in biology, such as cell biology, evolution and reproduction. Particularly for genetics, getting a thorough idea of meiosis serves as the foundation for understanding the genetic basis of inheritance, and how the product of meiosis become the source of genetic diversity (Quinn *et al.*, 2009).

The name "meiosis" was given by J.B Farmer and J.E.S. Moore in 1905 to state the reduction divisions that precede the formation of gametes (King *et al.*, 2013). Meiosis aims to produce daughter cells which own half of the parental number of chromosomes. This mechanism occurs as compensation for fertilisation. Without a process of halving the number of chromosomes through meiosis, once fertilisation has taken place, the new cell (zygote) will have twice as many chromosomes in the gamete. Since this relates to sexual reproduction, meiosis occurs during the process of gametogenesis which result in producing gamete, such as egg, sperm (animals) or spore (plants).

Meiosis is performed in two consecutive stages, meiosis I and II. Before the cell divides, it must first duplicate its genetic material through the process of DNA replication which brings consequences to the duplication of chromosomes. This process occurs only once. This is followed by the two-successive nuclear division, meiosis I and II. Meiosis I, which also known as reductional division, is the stage where the number of chromosomes is halved by allocating them into two separate daughter cells. Meiosis II, an equational division, acts further to distribute previously duplicated chromosomes in the daughter cells to two progeny cells. In total, four daughter cells will be produced by the end of meiosis, each containing half the number of chromosomes of their parental cell (Brown, 1992). Figure 2.1. showed the resume process of meiosis.

Table 2. 2. Ideas of fundamental concepts, common misconceptions, and new representations

No	Classification	Fundamental concepts	Common misconceptions	Example of resources which developed into teaching concepts
1	**The nature of genetic material**	1. Concept of gene 2. Correlation between DNA, genes, and chromosome	1. Defining genes based on classical genetics (a substance occupying a locus in the chromosome) 2. Genes and DNA are separate things 3. Genes are found only in certain cells, and different genes contain different genes 4. Incorrect understanding of the structure of the chromosome and what counts as one (Elrod, 2008; Smith, Wood and Knight, 2008; *Alternative conceptions about genetics,* 2017)	Using concept mapping in explaining the updating definition of gene (Gericke and Hagberg, 2007; Smith and Adkison, 2010)
2	**The structure of genetic material**	1. Structure of DNA 2. Structure of RNA	1. DNA is composed of protein 2. A twisting idea to the location within the cell where DNA and RNA can be found (Elrod, S., 2008; Harrell *et al*, 2005)	Performing DNA extraction and building representational models to learn the structure of DNA (Harrell *et al*., 2005)
3	**The reproduction of genetic material**	1. DNA replication 2. Mitosis and meiosis (cell division)	1. DNA replication occurs in the first stage of cell division (prophase) 2. In a semi-conservative model of DNA replication, double-helices DNA produces another copy 3. Having a representation of diploid as the duplicated chromosome, while haploid is merely seen as a cell having an odd number of chromosomes 4. Chromosomes' behaviour during mitosis is the same as in meiosis 5. Assuming a chromatid is a chromosome, and sister chromatids are homologous chromosomes 6. The incorrect mental representation of alleles (e.g. putting alleles in different locus, sister chromatids contain different alleles) (Kindfield, 1994; Kalas *et al*, 2013; Stewart, 1982; Smith, Wood and Knight, 2008; Elrod, S., 2008)	Genscope software programme (Horwitz *et al*, 1998; Luo, 2012; Clark and Mathis, 2000; Locke and McDermid, 2005)
4	**The inheritance of genetic material**	1. Mendelian (single gene) inheritance: concept of monohybrid, dihybrid	1. Misunderstanding that all traits are inherited through Mendelian genetics 2. Misinterpret probability in offspring, e.g. if the risk is ¼	An instructional material in teaching Mendelian genetics (Allchin, 2000), inverting curriculum to overcome a

		2. Multi genes inheritance: concept of pleiotropic (one gene determines many traits) and polygene (many genes determine one trait)	and the parents already have one affected child, their next three will be unaffected 3. Use Punnett square mechanistically, rather than conceptually, being less able to relate the representation of symbols with events in meiosis & fertilisation 4. Do not recognise the relation between meiosis and Mendelian Law (the law of segregation and independent assortment) 5. The term dominant implies that the affected phenotype predominates and most children will be affected 6. The particular condition cannot be "genetic" because it has not occurred before in the family of either parent 4-6: (Winsor, 1988; Stewart, 1982; Allchin, 2000; Nusantari, 2011)	simplified idea that all traits are inherited through Mendelian inheritance (Dougherty, 2010)
5	**The expression and regulation of genetic material**	1. Transcription and translation 2. Operon system 3. Promoter, enhancer and silencer	1. Traits are determined only by gene (no environmental influence) 2. The concept of one gene determines one trait (one gene one phenotype), 3. Genetic code (in the form of DNA) will be transcribed and translated into protein or polypeptide (central dogma) 4. Indicating transcription as translation, and vice versa (including the distortion between the products from two mechanisms) (Finkel, 2012; Forissier and Clément, 2003; Elrod, S., 2008; Aronson and Silveira, 2009)	Laboratory project using yeast to explain the pathway from gene to production of protein (Aronson & Silveira, 2009)
6	**The alteration of genetic material**	1. Type of mutation: based on location (point or chromosomal mutation) and effect (silent, non-sense, mis-sense) 2. Recombination and mutation	1. Every mutation will lead to change in phenotype/trait 2. There is no "good effect" of mutation 3. Mutation cannot be repaired 4. Mutation occurs at random, while recombination has a specific aim (Mills Shaw *et al*, 2008; Corebima, 2002)	Using databases to compare the genes for human and chimpanzee beta haemoglobin (Offner, 2010)
7	**The manipulation of genetic material**	1. Various methods in genetic engineering and their protocols 2. The principle of DNA fingerprinting, Isolating and using PCR, Cloning, DNA recombinant	1. Concept of "genohype" 2. Gene therapy is the technique for curing genetic disease 3. The idea of eugenics 4. Simplistic idea of how to perform any research in genetics (Mills Shaw *et al*, 2008)	An instructional activity to perform DNA profiling (Kurowski and Reiss, 2007)

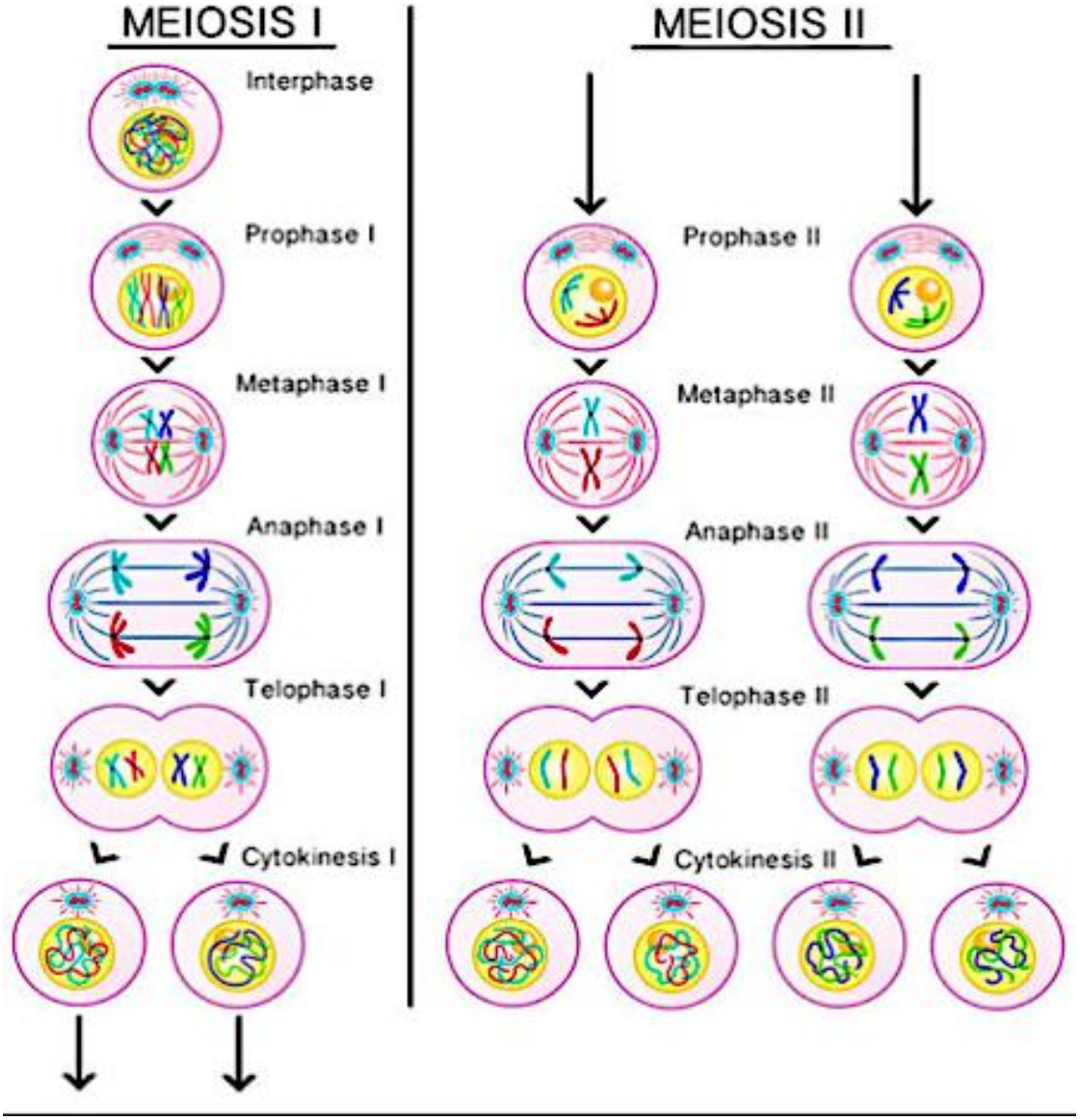


Figure 2. 1 Diagram of complete stage of meiosis. *Left: sequence of meiosis 1 consists of homologous pairing (prophase 1), homologous aligning on cell equator (metaphase 1) and segregating (anaphase 1), which concluded with two groups of chromosomes (telophase 1). Right: sequence of meiosis 2 consists of chromosome re-condensation (prophase 2), chromosome aligning on equator of cell (metaphase 2) which then segregating (anaphase 2) into single, unduplicated chromosome (telophase 2). Crossing over is depicted as different colour of homologous chromosomes after prophase 1 (adopted from Rabiya, 2019)*

The key factor in understanding meiosis lies in the behaviour of chromosomes at each stage. By focusing on events in the chromosomes, meiosis I could be differentiated further into four phases. Prophase I is the beginning phase. In this phase, chromosomes, which initially appear as thin threads, will condense and eventually become visible, rod-like structures. The chromosomes in this phase have been duplicated, therefore they already consist of sister chromatids. During the condensation process, the threads pair. This pairing, also known as synapsis, occurs between homologous chromosomes – the

duplication of chromosomes where one chromosome originally comes from the paternal and the other from the maternal gamete. The concept of "bivalent" is related to the situation in which condensation is in progress, in which the sister chromatids cannot be differentiated, while "tetrads" is a term for a pair of chromosomes showing four chromatids which can be clearly differentiated. Another important event in this phase is a type of localised breakage which is then followed by an exchange between non-sister chromatids, also known as crossing over. As the result of this event, each chromatid will contain a combination region of both maternal and paternal origin. At least one crossing over will occur in a pair of homologous chromosomes. When the two chromosomes in a pair begin to separate, the location of crossing over becomes noticeable. The overlapping chromatids form a cross-shaped structure called a chiasma (Pierce, 2010; Brown, 1992). According to King *et al.,* (2013), "*the chiasmata slip along laterally toward the ends of chromatids with the result that the position of a chiasma no longer coincides with that of the original crossover*" (p.281). This terminalisation proceeds, until all chiasmata reach the end of the tetrad, just before the segregation during anaphase.

The rest of the mechanism of meiosis I involves the arrangement of tetrads at the equator of spindle (metaphase I), and the separation of chromosomal pairs, from which each chromosome from a pair will go to a different cell pole (anaphase I) and the production of two gametocytes (telophase I). After a short interval, meiosis II commences. It begins with condensation, or coiling, of chromosomes if they had become uncoiled during the interphase (prophase II); the lining-up of chromosomes at the equator of the cell (at the metaphase plate (metaphase II)), the separation of chromatids from each chromosome (anaphase II), the passing to a separate cell (telophase II) (Pierce, 2010).

In short, King *et al.,* (2013) deduced that meiosis is important since it "*provides a mechanism whereby (1) an exchange of genetic material may take place between homologous chromosomes, and (2) each gamete receives one member of each chromosome pair*".

2.7.2. Single gene (Mendelian genetics) inheritance in focus

Mendelian genetics is often called transmission genetics because it deals with the study of the patterns of inheritance from generation to generation. Mendel's conspicuous contributions to explaining heredity are the notion that each parent passes on a separate,

distinct element of heredity (or, as he called it, a "factor") which contributes to its progeny, and to show that each of these parental factors remains unchanged as it is passed from one generation to the next. He found the principle of heredity using true breeding pea plants. A true breeding plant is characterised by the production of progeny identical to itself when self-fertilisation is conducted. The difference in one or more traits when the two true-breeding varieties are crossed constitutes a hybrid (Hartl, 2014).

King *et al.*, (2013) refers to Mendelian genetics as "*…the inheritance of chromosomal genes following the laws governing the transmission of chromosomes to subsequent generations*" (p.285). The two Mendelian laws are the law of segregation and the law of independent assortment. The former refers to how factors (in modern term, "genes") are segregated. In parallel with meiosis, this principle signifies the separation of alleles from a diploid parental organism into different gametes. The latter law states that two or more different genes assort independently during gamete formation. In a corresponding mechanism in meiosis, this principle is elucidated through the independent assortment of chromosomes. This close relationship between understanding Mendelian inheritance and meiosis is put forward by Knipples (2002).

Initially Mendel used the principle to explain the breeding process in pea plants, but a broad application of Mendelian inheritance was adopted, particularly in the platform of classical genetics (Allen, 2003). All sorts of characteristics inherited following Mendelian laws could be categorised as this type of inheritance. The characteristics are similar in terms of having a single gene controlling a single phenotype. In humans, genes which have this pattern of inheritance could be tracked using the Mendelian Inheritance in Man (MIM) catalogue (King *et al.*, 2013).

To understand Mendelian genetics, the learner needs to work on some related terms. Above all, understanding the concept of a gene is the most important, or at least to see a gene as a hereditary determinant of trait. Another crucial concept is understanding allele and genotype. Allele is defined as "*the different forms of a particular gene*". The common representation to alleles is a written letter or combination of letters, for example A, or a, and B, or b. An understanding of alleles plays a major contribution in compiling the mental representation of the genotype, the genetic constitution of an organism. For example, the independent assortment of two genes (symbolised by A, B) would produce four types of gametes (AB, Ab, aB, and ab). Apart from that, the learner needs to understand the terms dominant and recessive,

which control how the phenotypes are expressed. The dominant trait is the phenotype expressed if alleles are either heterozygous or homozygous, while the recessive trait is the phenotype expressed when alternative alleles are homozygous (Hartl, 2014).

In teaching genetics, focusing teaching material on classical genetics could lead students to think that single inheritance is the only way to transmit genetic material between generations (*ScienceHub*, 2017; McElhinny *et al*, 2014). However, teaching this simple pattern of inheritance is not without problems. Misunderstandings about the probability of offspring (Mills Shaw *et al*, 2008), and difficulty in relating a symbol in Punnett square with events in meiosis (Stewart, 1982), become apparent issues which need to be resolved.

2.7.3. The central theme of genetics: the concept of the gene

The gene is the central theme in genetics – everything in genetics is related to the gene (Corebima, 2002). However, the definition of a gene is changing with new research findings in genetics. Even among scientists in different fields, defining gene becomes challenging. How population geneticists define a gene is different from how developmental biologists define the same term (Slack, 2014). Moreover, the term gene is changing with the advanced findings of the HGP (human genome project) and the ENCODE project (Gerstein *et al*, 2007; Pesole, 2008). Understanding the definition of a gene will bring students' understanding of how a gene has been defined differently over time, in classical genetics (the Mendelian and post-Mendelian era), at the beginning of the molecular era, which led to the central dogma paradox – seeing a gene as a sequence of DNA, and later proposing that the term gene is abstract, since the rise of RNA's contribution to controlling traits/phenotypes (Smith and Adkison, 2010; Falk, 2010).

The definition of a gene has changed as advances in genetic analysis and technology have enhanced our understanding of its structure, function, transcription, and genomic organisation. In the classical literatures, a gene is defined either as an hereditary unit that occupies a specific position (locus) on a chromosome, or as a unit that has a phenotypic effect, or a unit that can mutate to various allelic forms, and that recombines with other such units in a genetic cross (Pearson, 2006; Smith and Adkison, 2010). With the elucidation of the molecular nature of DNA, and information from molecular biology and sequencing technology (mid to late 20th century), a gene is viewed as a hereditary unit composed of nucleotide sequences (including 5' and 3' untranslated sequences and introns) that are required for the production of functional

protein or RNA products (Hartl, 2014). Thus, a gene can be identified based on sequence characteristics, transcription, or homology to the known gene. Using a computational tool uncovers the extensive and overlapping networks of transcription (including noncoding RNA) which pose a challenge to the existing definition of gene. A gene can overlap another such that the same DNA sequence codes for two different products in different reading frames or on opposite strands; a noncoding RNA can be transcribed from the intron of – or antisense to – a protein-coding gene; a gene can have multiple transcription sites; and a gene can have distant regulatory regions, or those it shares with other genes. The evolving definition of a gene becomes: "genomic sequences that are required, in sequential or overlapping combinations, to produce one or more functional RNA or protein products that contribute to a particular phenotype" (Gerstein *et al*, 2007).

Chapter 3 - Research methodology

Overview

This chapter is intended to provide an explanation of the methodologies and methods used in this study. The action research approach used in this study is discussed in the research design section. It continues with a description of methods used in collection and analysis of data. The chapter is concluded with a discussion of ethical issues.

3.1 Research context

This study focuses on the development of targeted educational resources addressing basic concepts of genetics at the undergraduate level (see Chapter 1). The educational resources were developed using information on common misconceptions published in a number of studies (see Chapter 2). The educational resources were aimed at countering misconceptions of the basic concepts of genetics by undergraduate students. The effectiveness of the resources was evaluated in two context-cases, (1) students of the Biology Education Programme at the Universitas Tanjungpura, Indonesia and (2) biological sciences students in the College of Medicine, Biology, and Psychology at the University of Leicester, United Kingdom.

3.2 Research Design

The development process for the educational resources, which was the focus of this study, involved two important elements: the action of the development, and the evaluation research. The efficacy of the resources was evaluated through analysis of their effectiveness in allowing students to attain better conceptual understanding of the genetics' fundamental concepts of interest. The terms of making "changes" to the students' conception through an "action" in creating educational research and "research" to the resources effectiveness suggested the adoption of Action Research (AR) approach in conducting this study.

Action research is an approach initially developed by Kurt Lewin in 1948 to imply changes in social practice (Dickens and Watkins, 1999). The potency of applying action research approach in education can be related to the work of Stenhouse in 1975 and Carr and Kemmis in 1986 (Atkins and Wallace, 2012). Stenhouse's suggestion for the use of a "research-based mode of teaching" (Atkins & Wallace, 2012, p. 126) emphasised the need for teachers to research their own work signified the beginning of the era of education action research in the UK. Carr and Kemmis brought the education

action research into the area of conducting self-reflective practice in order to improve the practice, the understanding of the practice and the situation in which the practice takes place (ibid,: 126-127). Here, Atkins and Wallace, (2012) proposed the term "self-reflective practice" would be better called "self-reflexivity" since the implication of action research was not only on personal development, but also to include professional development and growth. "*Reflexivity demands that the researcher reflects on and evaluates not only their own impact on the research, but also how such things as personal values, past experiences, attitudes, and assumptions might impact on the research*" (p.127).

Cohen *et al.*, (2011) emphasised that the attractiveness of the action research approach to the educational (e.g. teachers) and general academic community (e.g. researchers) was on the practical use of the "doing" action while researching. The practical side of action research makes it fit for use in any setting, as long as there are problems involving "*people, tasks, and procedures*" (p.344) which demand an action to solve, or else where there is an implementation of changes may lead to a "*more desirable outcome*" (p.344). The change arising from the action research could either be centred on the changes to a social group (for example students in a class, curriculum) or on the changes to the researcher (for example teachers who perform the research). The first change was based on the work of Lewin which then developed as the Participatory Action Research (Kemmis and McTaggart, 1992), while the latter change was based more on the individual reflective side of the Action Research (McNiff and Whitehead, 2011).

Action research can also be defined based on the different focus between researching the impact of action and the making action through researching. The former definition of action research was shown by, for example, Cohen and Manion (1994), p. 186: "*a small-scale intervention in the functioning of the real world and a close examination of the effects of such an intervention*". Another definition on the same focus of attention was given by Kemmis and McTaggart (1992) p.22, "*action research is an approach to improving education by changing it and learning from the consequences of changes*". The latter definition of action research was provided by Somekh (1995), p.340, "*action research is designed to bridge the gap between research and practice, thereby striving to overcome the perceived persistent failure of research to impact on, or improve, practice*".

Despite differences in definition of the term "action research", the words *action*, *research*, and *change* always appear. This signifies that action research is an approach that combines an action during or through researching to implement a change to a local community. However, Atkins and Wallace (2012) suggested making a clear boundary between the change in action research and routine incremental changes to teachers' day to day practice. The latter referred to the continuous adjustment to planning teaching based on evaluation and reflection on the previous teaching plans. Although this cyclic process of change is the basis of action research, it could not be so unless the changes are informed by a theoretical framework which was based on the research literature. Thus, the different between regular change (here, it is called "*action enquiry*" p. 127) and action research lies in the use of theory to inform the action process.

The action research procedure involves the use of action and reflection in turn (Costello, 2011; Cohen et al., 2011; McNiff and Whitehead, 2011). With the extensive application of action research, many models of action research have been developed (reviewed by Costello, 2011 and Cohen *et al*., 2011). However, all models were based on the four-step procedure suggested by Lewin (1946). The four main stages were: planning, acting, observing and reflecting. Lewin (1946) suggested that the study commenced with a general idea based on specific situational problems. This stage led to the production of an action plan to reach the identifiable goal (planning stage). The implementation of the plan involved steps taken in carrying out the planning (acting stage). The steps in implementation could be the same as, or modified from, the planning stage. However, the steps were all monitored or evaluated (observing stage), which led to revised planning and the procedure of implementation (reflecting stage). This was reiterated in the next cycle of implementing, planning and monitoring actions.
Developing resources for teaching is a regular task for teachers and instructors involved in conducting instructional programmes (Kemp, 1977; Gagné *et al.*, 2005). In so doing, it involves the reiterative process of creating and evaluating resources which correspond with the stages of action research. Following the four steps of action research by Lewin (1946), the planning step of this study consisted of searching published literature related to common misconceptions which occur in many classes in the world in order to anticipate detecting the same problems within the local situation (participants in this study). This was based on the idea that similar characteristic misconceptions occur for many students in different educational settings and at different levels of education across the world (Fisher and Moody, 2000). An action plan related to overcoming such

misconceptions was devised, which was then implemented in the creation of educational resources (the acting stage). Following the creation of these targeted resources, an investigation of their effectiveness in achieving the goal of promoting students' understanding of the concept by reducing the misconceptions (the observing stage). The results of the evaluation acted as the reflection material preceding improvements in planning and procedure in developing the resources (the reflecting stage). Figure 3.1 summarises the steps in producing targeted resources by adopting the action research approach.

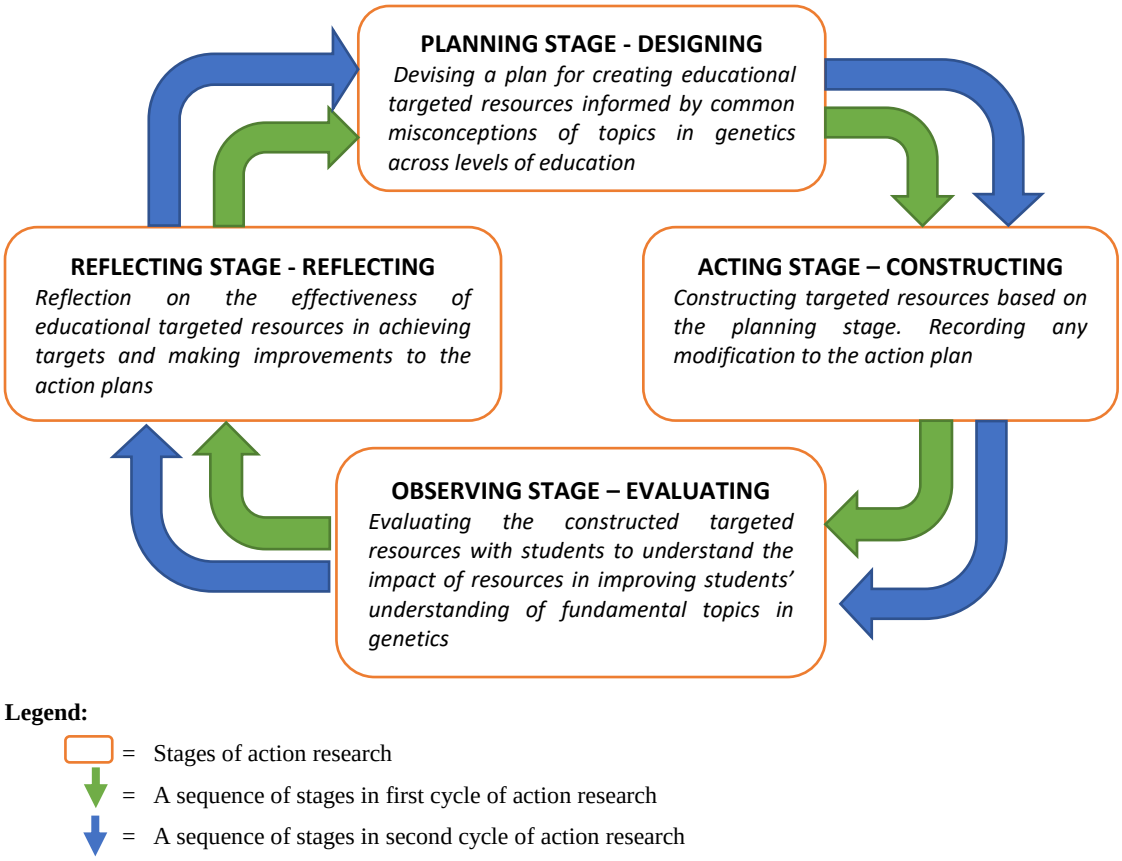


Figure 3. 1 A *model of action research for developing targeted resources following the four steps of action research proposed by Kurt Lewin (1946).* *There are two cycles in the model showing the cyclic nature of action research. The corresponding stages in developing targeted resources to the stages of Lewin's action research were given as a title of each stage ( ). The first cycle of action research ( ) begins with planning stage and ends with the reflecting stage. Reflection of the first cycle inform the planning stage of the second cycle which carried out through the stages ( ) up to the reflecting stage. The latter inform the next action planning of another cycle of action research.*

3.3 Interpretive Paradigm

Cresswell (2003) argued that this type of action research should be conducted under a pragmatic paradigm, where both quantitative and qualitative paradigms are used in the

same research, leading to the application of mixed methods. However, many other authors suggest the use of a qualitative approach (Costello, 2011; McNiff and Whitehead, 2011; Patton, 1990; Stringer, 2014). They argued that using a positivist stance (the quantitative paradigm) may not be well suited to understanding the "change" since it would need a deep understanding which would be more contextual or situational. This view is substantially highlighted by McNiff and Whitehead (2011) since they believe that the fundamental "change" occurs in the researcher and to explain the experience of this "change", the researcher must use an interpretative scheme. However, Stringer (2014) does not restrict the data, which should all be in qualitative forms, since some quantitative data could be used to support qualitative analysis, particularly with the benefit of triangulation.

Compared to the quantitative, the qualitative paradigm offers a comprehensive approach to investigating social phenomena. Merriam (2009) noted that this comprehensiveness comes from the ability of the qualitative paradigm to capture and reveal how people interpret their experience of an event being studied. As research in this current study involved investigation into conceptual understanding promoting use the resources developed here, students' perceptions would be as beneficial as data. These perceptions are most useful in understanding how people view and experience using the resources, and the researcher acts as an instrument to reveal and interpret this phenomenon (Strauss & Corbin, 1998). In this case, quantitative analysis did not give comprehensive explanations. In addition, Creswell (2007) related the complexity of phenomena to multiple factors that direct the event, e.g. feeling, attitude, behaviour and value and therefore suggested that knowledge obtained by using this approach would depend on the context of the event. As Newton (2011) had identified multiple factors contributed to learning behaviour, i.e. "*assortment of conceptions, abilities, skills, knowledge, interests, attitudes, beliefs, aspiration, expectations, and preferences*" (p.11), the qualitative paradigm enables a researcher to consider all factors involved in analysis of the data.

3.4 Participants

The observing (evaluating) stage of this study involved testing the targeted resources to two groups of students; students in the Biology Education Programme, at the Universitas Tanjungpura, Indonesia (is referred to as the Indonesian case across chapters in this thesis), and biological sciences students in the College of Medicine,

Biology, and Psychology (CMBSP), at the University of Leicester, UK (is referred to as the UK case across chapters in this thesis). The use of two groups of participants in this study, taking different degree programmes and at more than one location, acted as a useful tool for investigating the effectiveness of targeted resources, informed by common misconceptions, in order to solve common problems faced by genetics students across the world.

All participants were undergraduate students who were taking a genetics module or had just finished their genetics course at the time the evaluation stage of this study. In the case of the Indonesian students, a genetics module was offered in their third year of study (Pendidikan Biologi, 2014) meanwhile for the UK students it was delivered in the first year. Thus, in this investigation, the comparison was made between the Year 3 Indonesian Biology Education programme students and the Year 1 UK Biological Science (Genetics)/Medical Genetics students; these students were covering equivalent topics of interest (the fundamental concepts) in their genetics courses.

The targeted resource were developed in two cycles (except for the Inheritance cards for which only one cycle was possible (see Chapter 5) involving students in Indonesian case in two different academic years and students of UK case in one year of the development cycle. Due to the different starting times for developing resources, the evaluation process involved three groups of Indonesian students over three different academic years, and one group of UK students in a single academic year.

Each group of students had different characteristics relating to number of students involved in the study and phase, relating to the completion of their genetics modules at the points at which the study was conducted. This was due to availability of participants at appropriate points in their academic programmes. Below are their specific circumstances related to this study.

1) Indonesian students case 1 (IND-1)

Participants for the first case (IND-1) were Year 3 biology education students at Universitas Tanjungpura taking their genetics module in the academic year of 2015/2016. The genetics module was offered in the first term (equivalent to the autumn term) of that academic year. They were involved in evaluating the video resource illustrating meiosis. Sixty-six (66) students participated contributed to a general understanding of concept attainment for meiosis by taking the Pre-test. From that number, 28 students participated by watching the video and then did the Post-test. However, only 17 of these participants completed all stages of research including the

post interviews. Due to the need for data triangulation between interview and test, the number of participants was considered to 17 participants for this respective cohort.

At the time of the data collection, the participants had completed the genetics module (KPB425) with a minimum grade of C (scored 60-70 in the scale of 100) and were taking an evolution module (KPB426) at the time of the study. The genetics module covered various topics of genetics, including meiosis which was discussed as part of genetic transmission (inheritance). Concepts of meiosis and mitosis were discussed at the same time, just before the explanation of Mendelian inheritance.

2) Indonesian students case 2 (IND-2)

Participants for the first case (IND-1) were Year 3 biology education students at Universitas Tanjungpura taking the genetics module in the academic year of 2016/2017. The genetics module was offered in the first term (equivalent to the autumn term) of that academic year. They were involved in evaluating video resource illustrating meiosis (second cycle), the inheritance cards (first cycle) and the booklet of the gene concept (first cycle). Seventy-eight (78) students from three (3) parallel classes of the Genetics module participated in constructing general understanding concept attainment for meiosis and Mendelian inheritance through conducting Pre-test. The gene concept test was given only to the participants and not to the whole cohort. The number of participants involved in evaluating each resource was different, see section 4.3.3, 5.2.3, and 6.3.3 for the detail number. At the time the study was conducted, students were preparing for their genetics module (KPB425) final exam. They had covered all related topics of interest in this study, meiosis, Mendelian inheritance, and the concept of gene in their module.

3) Indonesian students case 3 (IND-3)

Participants for the first case (IND-1) were Year 3 biology education students at Universitas Tanjungpura taking genetics module in the academic year of 2017/2018. The genetics module was offered in the first term (equivalent to the autumn term) of that academic year. They were involved in evaluating the concept of the gene booklet (second cycle). Initially, ten (10) students volunteered to be involved in this study. Due to a health issue for one of the participants, only nine (9) students took part in the whole investigation and so only these nine were considered as participants for this study. When the study was conducted, students had taken their genetics module (KPB425) final exam and were waiting for their results. They had covered all related topics of

interest in this study, meiosis, Mendelian inheritance, and the concept of the gene in their module.

4) UK students (UK)

Participants for this cohort (UK) were Year 1 Biology Science (Genetics)/Medical Genetics students at University of Leicester taking genetics module in academic year of 2016/2017. An introductory genetics module was taken in the second term (spring term) of that academic year. Despite support from lecturers and sending several invitations to participate in the research to students, only two (2) of them consented to participate in this study. The low involvement of students for this case was thought due to the time of research conducting at nearing the end of both their academic term and of this module. Although the number of participants was low and there was a risk of making generalisations by comparing this case with counterpart cases in Indonesia, the UK case still gave valuable input for the resource evaluation as shown in the findings chapters (Chapter 4, 5 and 6). The two students involved in this case were studying Biological sciences (genetics) and Medical Genetics. They both were preparing for the final examination of genetics module (BS1050) when the study was conducted.

3.5 Data collection methods

This study was conducted by using a combination of four methods as suggested by Creswell (2007). These four methods are interview, audio visual recording, document collection and observation. Document, in this study, refer to researcher journal of resource development. Interviews were targeted at university instructors who were involved in the genetics modules and students taking these classes. Observation was targeted to students during their interaction time with the resources. In addition to all qualitative data, this study also used quantitative data of relating to students, in the form of conceptual tests. Quantitative data collection in qualitative studies was acknowledged by Stringer (2014) in assisting the researcher's interpretation. Venville and Donovan (2007) also give an example of adopting this approach in their research.

3.5.1 Conceptual test

The test served to investigate students' changes in their conceptual understanding after using the specific developed resources. Tests were taken from established concept inventory tests or other tests with similar function. Unlike formative or summative testing, concept inventory tests were developed specifically to measure students'

understanding and to identify misconceptions (Garvin-Doxas et al., 2007). However, the coverage of concept inventory in basic concepts in biology is still limited. Using validated tests gave two benefits. First, the established tests (MCI (Kalas *et al*, 2013) and GCA (Smith *et al.*, 2008)), did not need further validation prior to using them with participants. Second, the extensive data from the MCI and GCA studies provided a source of standardised results to compare to data from the participants of this study. These are multiple choice tests with one or several correct responses for each item (MCI, Appendix A-1) or a single correct response for each item (GCA, Appendix A-3). Both tests were translated into Indonesian language (Appendix A-2 and A-4, respectively) when applied to Indonesian cohort. Another test (gene concept test) was created specifically to elicit students' concept of gene (Appendix A-5, A-6). The details of the characteristics of each test and how they were used in this study is described in section 4.3.4 (Chapter 4), section 5.2.4 (Chapter 5), and ,6.3.4 (Chapter 6) respectively.

3.5.2 Observation

Observation was one of the qualitative methods used in this research. Observation is conducted on order to get "… *ideas about how particular types of people are likely to behave in particular circumstances*" (Foster, 2006). Unlike interview, observation has the advantage of getting information without relying on the participants' retrospection, which means that it gives an insight into the natural behaviour or responses of participants under specific circumstances or contextual setting. Moreover, it also gives the observer a chance for noticing an event which is difficult to describe by the subject or the things that they were not willing to talk about (Foster, 2006; Merriam, 2009).

However, the importance of using observation method in this study lies in the function of observation as the cross-check point or additional evidence to the information obtained by other methods, as suggested by (Foster, 2006). He gave an example for doing a comparison between behaviour claimed by interviewees with their actual behaviour under observation. Using observation, in addition to interviews about students' conceptual understanding and their perception of the resources, acts as a triangulation method as well as a technique to gain validity of what they said in the interview. This is important, for example to cross-check students' claims of their engagement with the resources and their actual behaviour during trialling them.

In conducting observation, the researcher adopts the role of participant observer (Sapsford and Jupp, 2006). This technique enables the researcher to build a relationship

and trust with the subject of observation which enables collection of data which are "*…more concrete and more strongly oriented to the essential aspects of the research question*" (Flick, 2015). As suggested by Foster (2006), the key-point of doing participant observation is to try to "*see the social world as far as possible from the actor's point of view*" (p. 63). He continued that data obtained using this approach were not meant to be used as large-scale comparative data on particular behaviours, but more suitable to get more detailed information on the behaviour of particular individuals or groups in particular settings which match with the aim of conducting observation in this study. The advantage of using this approach is also in producing data with less reactivity by participants, that is, observing the subject response as naturally as possible, because they are less suspicious and less resistant to the presence of the researcher, while at the same time maintaining the position of researcher as observer.

This approach is characterised by establishment of a relationship between the researcher and the subject of observation. Foster (2006) explained that making relationships is about the way we want others to see us, or how we represent ourselves. In this study, the researcher approached students in both cases by representing herself as a student-researcher who was interested in studying the effectiveness of the resources. This was done to create a comfortable situation when they were observed whilst they were working/learning with the targeted resources. In this case, the role of researcher was not becoming the instructor or a colleague of their instructors (particularly in the Indonesian cases) who would have power to determine their success in finishing the module. Within this circumstance, a more honest and reliable evaluation was gained, which may be different from the result if they were observed by their own tutor or instructor.

Observation was made of students during their interaction with the resources. They were working either in pairs (for evaluating the booklet "concept of gene") or groups of 3-4 in conducting the evaluation following the activity of watching the video resource or using the inheritance cards (except in the UK case where only to only two participants were involved). The Indonesian students were grouped randomly. A non-random assignment was used to assign the male students into different groups in evaluating the inheritance cards. This was done to distribute the limited number of male students more evenly. Observation was supported by recording the students' conversations in the groups in addition to the general notes made from observing groups of students conducting their activities as suggested by Foster (2006) to involve other

senses (such as hearing) in the observation. The researcher also assisted groups who requested help. In the case that no questions were posed, the researcher spent some time with individual groups to observe how students interacted with the resources. No intervention was made to students' work unless it was related to misunderstandings of the procedure, for example to correct students' understanding of instructions for conducting a simulation with paper models of chromosomes, where they were joining paternal and maternal chromosomes into one duplicated chromosome (see Chapter 4 for detail).

The audio-recorded conversation of a group or a pair during observation was analysed together with the notes to get an insight of how individual students responded to the resources, and how they engaged in the group task. This also aimed to get evidence of any conceptual understanding or any conceptual change that took place during their work. Hoban (2007) gave such an example of depicting conceptual change by analysis of an excerpt of a conversation made by thinking aloud methods during a task, which prompted the use of a similar technique in this study.

3.5.3 Researcher journal analysis

The term "documents" in qualitative study refers to a broad selection of "printed and other materials relevant to a study, including public records, personal documents, popular culture and visual documents, and physical artefacts" (Merriam, 2009). This term suggests the use of "existing material" (Flick, 2015) which was already available and therefore are more resistant to bias because they are "unaffected by the research process", yet they are "grounded in the real world" (Merriam, 2009). Despite the understanding that documents are collection of any material which exists before the research is conducted, it is not impossible to consider the type of document which is purposively generated for research. These researcher-generated documents are acknowledged as a valuable source in qualitative inquiry (Merriam, 2009; Flick, 2015).

This study used these two types of documents as sources of data; a researcher journal made to record every change in the developing process of resources, and the students' worksheets which were completed as part of the task related to the targeted resources. The research journal could be categorised as a personal record document (Merriam, 2009) as it documented the ideas, actions made, and the beliefs during developing resources, however, since it is specially made for this study, it falls into the category of researcher-generated documents according to (Flick, 2015; Merriam, 2009).

(Borg, 2001) pinpointed the use of the researcher journal in a study in term of process and product. The journal acted as the place for recording every exploration and discovery of any ideas and thoughts which could be useful in reflection and in interactively supporting the understanding of the project. As a product, a research journal acts as evidential storage for every step in the project which could be analysed retrospectively. The aim for collecting data from a journal was part of reflection which could be used to examine the gap between researcher intended purpose of resources and the target students saw while they were using resources as part of their learning process.

3.5.4 Interviews

Interviews were conducted to determine the students' points of view of the experience of learning with the resources and to identify any conceptual changes in understanding of the fundamental genetics concepts of interest learned. Patton (1990) put forward that this method was particularly suitable to document "*feelings, thoughts and intentions... behaviours that took place at some previous point in time...situation that preclude the presence of an observer"* (p. 278).

Interviews were conducted to find out how the specific resources, which were developed to teach basic genetics concepts of interest, contributed in tackling students' misconceptions, and promoting students' comprehension of those particular topics. These interviews were conducted after letting students interact with each learning resource. The questions for this part focused around their views on how resources assisted their understanding for particular subjects, and for measuring their conceptual understanding status after learning using the resources.

All interviews were conducted using a face-to-face interview approach. Using this technique students, were given a chance to communicate their perceptions without feeling intimidated by other participants' presence. Interviews were scheduled based on students' free time. In order to obtain a useful result, interviews were set in a relaxed, comfortable environment as suggested by Brinkmann and Kvale (2009). In this case, interviews were conducted by starting with greetings and a short briefing about the purpose of interview before commencing the recording.

The interviews adopted a semi-structured approach (Gillham, 2005; Merriam, 2009). Within this approach, all questions used in the interview were referenced to the set of questions in the guidance, although the order or the choice of words could be different, based on the natural flow of conversation in the interview. The interviews

were audio-recorded for further analysis. The semi-structure interview instruments for the three targeted educational resources were made available both in English and Indonesian (see Appendix A-7, A-8).

Patton (1990) explained that the purpose of interview is to "*find out what is in and on someone else's mind*" (p.278). The purpose of conducting the post interview was to gather information on a student's learning process while using the resources. The interviews had two foci. First, they were conducted to identify participants' views on how they thought the resources had assisted them in learning the targeted concepts. This first part was done by asking them about any detail they remembered of their experience with the resources, including the points that attracted them to engage with resources and also any things they found difficult to understand during their interaction. The questions in this part invited them to think retrospectively about the event they had experienced. Second, interviews were conducted to investigate students' conceptual understanding of the concepts taught in the resources by exploring any conceptual changes they thought they had had, and by asking them to explain the concepts using their own words. The latter approach was also used to evaluate the way the resources had assisted students in learning the targeted concepts. For conducting the latter part, pictures, diagrams, and their responses in the concept test became the starting points for discussion, a technique known as elicitation technique. Martins and Ogborn (1997) used this particular technique in their study of metaphorical reasoning in genetics. This technique is particularly useful to retrieve participants' reasoning behind the conceptions they have on particular topic.

The data collection for each focus of study may be summarised as follows.

1. *Designing targeted resources (Planning stage, first cycle)*

Before creating resources on basic concepts of genetics, a thorough analysis was conducted to decide which basic concepts were to be the focus of the new resources, and which kind of misconceptions in the related concepts would be targeted. The curriculum and syllabus analysis (from the comparative part of the study) was used to examine curriculum needs for basic concepts of genetics. In addition, various schemes of understanding for core concept of genetics which were put forward by Corebima, (2002) and Griffiths and Mayer-Smith (2000) were also applied in order to assist in selecting prominent fundamental concepts in genetics.

Extensive literature review on various misconceptions in genetics acted as sources to determine misconceptions linked to each basic concept in genetics. Documents which fell in this category were research articles containing information on problems in understanding genetics (e.g. (Kindfield, 1994), and concept inventories or other similar tests which reveal the barriers for understanding related concepts in genetics (e.g. (Kalas, O'Neill, Pollock, and Birol, 2013; Bowling *et al*, 2008)). From analysing this literature, common misconceptions in basic concepts of genetics were found. This review can be found in the Literature Chapter 2, section 2.7 discussing each resource in this thesis.

The design stage of resources also considered the appropriate format for the resource. Any available resources on-line, such as those presented on Youtube™ or on other biology or genetics educational websites, and off-line, such as any report on creating resources, were analysed to give the information on the current state of resources and the issues yet needing to be resolved. Discussions with colleagues, reflecting on their experience of teaching the basic concepts of genetics in the two countries (UK and Indonesia) also played a role in determining concept and content selection for the resources.

This preliminary analysis led to the design of resources on the four core concepts in genetics, i.e. meiosis, single-gene inheritance, gene expression and mutation, and the concept of a gene. The initial resources were designed to challenge common specific misconceptions, and this was reflected in the format chosen for each resource.

2. Developing learning resources (Acting stage; first cycle)

The development process for resources included several steps conceptualising the planning into the scenario/script and creating prototype of resources. The prototypes were discussed several times with GENIE members which guided the revision and improvement before the physical resources were made. All steps in developing resources were recorded in the journal of research.

The resources were targeted to improve the conceptual understanding. To measure the students' understanding, qualitative instruments were also constructed. Two instruments were prepared, i.e. interview guidelines, including the development of diagrams and other materials used as sources for discussion in the elicitation technique, and the format for observation notes. All instruments were piloted to ensure their applicability prior to data collection (Gillham, 2005).

3. *Evaluation of learning resources (Observation stage; first cycle)*

This stage consisted of implementing resources in the two cases (Indonesia and UK), and observing the learning implications. Participating students in this stage were the same students which were involved in the comparative study. Prior to using each resource in the learning process, participants were given the conceptual test (both MCI and GCA). Their interaction with the resources was observed and audio or video recordings made. Observation notes were made during the process. As soon as the activities were completed, students were given the same test again. Interviews were conducted within a range of one week after they had used the resources. All interviews were audio recorded. The detail of steps in data collection for each resource will be presented and discussed in the appropriate finding chapters.

4. *Evaluation of learning resources (Reflection stage; first cycle)*

Data which were collected in the previous stage were analysed. All interviews were transcribed verbatim and analysed using the method of content analysis through two cycles of coding (Miles, Huberman and Saldana, 2013; Saldana, 2015). Data from observation notes were correlated with the excerpts from conversations between students in the group whilst using the resources. The test data gave a confirmation on the finding from the interview and observation about students' conceptual understanding and their perception toward the resources. The three types of data collection act as a triangulation in the qualitative research. All data were contributed in the evaluation of resources. The evaluation led to the reflection to the developed resources and act as a basis point for revision.

5. *Refinement of Learning Resources (Planning stage; second cycle)*

By adopting the Action Research paradigm, reflection on the first cycle acted as a starting point for making corresponding revisions for second cycle (Cohen, Manion and Morrison, 2011; Costello, 2011). In this stage, any redesign of resources took place by modifying the initial plan, improving the content of the resource, and by dealing with any technical issues. However, the formats of resources remained unchanged.

6. *Redevelopment of the Learning resources (Acting stage; Second cycle):*

This stage involved the re-development or revision of each resource according to the plans made in the initial stage of the second cycle (see 5, above).

7. *Evaluation of revised learning resources (Observing stage; Second cycle):*

The same instruments as in the first cycle were used in this stage of the research. Participating students were different from those involved in the first cycle, however

they were at the same stage and taking similar modules as the previous groups of students. The procedure in collecting data for the second cycle was the same as the protocol in the first cycle (see 3 above).

8. Evaluating revised learning resource (Reflecting stage; Second cycle):

Reflection was made during the process of data collection and analysis in the second cycle. This reflection centred on how the developed learning resources influenced students' conceptual understanding of the genetics basic concepts. This was used in making a recommendation for further work.

3.6 Data analysis

Data in this study was analysed using content analysis. All verbal data were transcribed before analysis.

3.6.1 Document and interview data analysis

All verbal data form interview were transcribed into text before analysing and interpreting, following the methods of (Flick, 2015; Miles *et al.*, 2013). The interview tapes were transcribed verbatim as soon as possible after data collection. At the point where there was some uncertainty as to what students were referring to in their conversation, a check was made with notes taken during the interview and/or diagrams drawn by students during the interviews.

Miles *et al*., (2013) suggested the use of coding to analyse the content of conversations as well as the documented text, this approach is called content analysis. Coding is the essential part in qualitative data analysis to find a pattern which eventually led to the general themes to make a grounded theory (Strauss and Corbin, 1998). A code in the qualitative research refers to "*…a word or short phrase that symbolically assigns a summative, salient, essence capturing, and/or evocative attribute for a portion of language-based or visual data*" (Saldana, 2015). This code is determined by the researcher as the translation tool to give a meaning to an event of interest.

Miles *et al.,* (2013) and Saldana (2015) suggested two consecutive steps in carrying out coding; the first and the second cycle coding. The first cycle coding was conducted to categorise any information learned from the qualitative data. Saldana (2015) pinpointed twenty-five approaches to first coding which could be used in combination. The use of provisional coding was adopted as one of the coding methods for the content analysis for the interviews. Provisional coding was made with the basis

of researcher codes generated before the analysis take place. The anticipated code was made based on the previous research in the same field. This step was used particularly for analysing the conceptual understanding. Chi (1997) showed the practicability of using this method within the example of conducting top-down orientation in the analysis of conceptual change study. This method was used in conjunction with the deductive methods described by Miles *et al.* (2013) for conducting the provisional coding. The revisions to the coding took place before the second cycle of analysis. The procedure of conducting the first coding and then revising the existing one, is similar to the method of conducting the open and axial coding of Strauss and Corbin (1998).

The second cycle coding was done to find any patterns ("*repetitive, regular, or consistent occurrences of action/data that appear more than twice*" (Saldana, 2015)) in the data. This step was a way of generating a theory about how particular resources helped to promote students' conceptual understanding of the basic genetics' concepts. CAQDAS (Computer Assisted Qualitative Data Analysis) was used to manage and analyse qualitative data from interviews by using NVivo software tools (ver. 12). In addition to support of coding, NVivo also support the data query which retrieved all relevant information to answer the question (Bazeley and Jackson, 2014).

While analysing and interpreting data for interview, a tabulation technique was used. In the individual student analysis table, findings from observational data and conceptual tests were combined as methods for verification of findings from interviews and to give a holistic understanding to the students' conceptual knowledge. Matrices were used as one of the methods of displaying data as described by Miles *et al.*, (2013).

3.6.2 Observation data analysis

In analysing the data obtained from observations, two techniques were used. First, full written reports of the field notes were made and these were then coded using the second cycle of coding, using the method of Miles *et al.* (2013). Second, selected sections (related to the analysis of their conceptual understanding and views on resources) of recorded students' conversations from the resource evaluations were transcribed. Instead of conducting the typical full transcription of recording to text, Miles *et al.* (2013) also described conducting selective partial transcription by giving the example of *"…the field-worker listens or watches the recording, make notes, select excerpts, and if applicable, makes judgement or ratings"*. This approach was chosen to reduce unnecessary transcription.

The supporting information for observational data was also derived from analysis of students' worksheets. These latter data were analysed qualitatively to reveal a construction of students' conceptions of particular topics. This was used as a clarification for picturing students' learning processes. For the drawing task in the resource on the "concept of a gene", the method of conducting memo (Miles *et al.*, 2013) was used following the method of interpreting drawings of Chin and Teou (2010). Data from the worksheets were tabulated by individual student as an interpretation of their conceptual understanding. For a group task, it was assumed that the worksheets were done individually by all the students in the group, and the responses indicated individual students' understanding.

3.6.3 Data analysis for concept tests

Concept test results were analysed qualitatively. The change in students' overall scores between pre and post-test was particularly informative but based on the individual changes in response to each question, gave more useful data on changes to conceptual understanding. A justification for their understanding regards to the concept of interest was given by triangulating concept test data with interview data concerning the same concept. The reason for comparing the qualitative analysis to the test was used to highlight improvement on specific concepts following use of the resources. Further data analysis for each testing is presented in sections 4.3.4, 5.2.4, and 6.3.4 in this thesis.

3.6.4 Data triangulation

Data triangulation is one of the methods to verify findings through patterns matching several data sources. The triangulation of data could be achieved by using different sources of data (e.g. different time or places), applying different methods (e.g. interview and observation), involving other researchers or investigators, adopting different theories, and using combination of data types (e.g. qualitative and quantitative data) (Miles *et al.*, 2013). In this study, triangulation of data was attained by the application of two methods to measure the same phenomenon, students' understanding of a topic (test and interview), and students' perception to the educational resources (observation, interview). The validity of data analysis is obtained through involving research collaborators (supervisors) in generating coding and discussing the data tabulation analysis.

3.7. Ethical issues

It is important when conducting action research, that ethical issues are explored (Atkins and Wallace, 2012; Lichtman, 2013). Atkins and Wallace (2012) particularly emphasised the importance of handling the issue with insider research, while Licthman (2013) gave on the following principles of ethical conduct in qualitative studies: the study must not harm participants and maintains their privacy; the identity of participants must be anonymised; all data must be stored and reported in a way that respects the confidentiality of participants; participants must be asked to give informed consent at the start of the study; and researcher need to have a good interaction with participants by being friendly and empathy to them during the study.

In each case, before research started, students were informed clearly about the purpose of study and what would be done in data collection, analysis and reporting through the invitation letter (UK case), and direct explanation in the classroom (Indonesian case). Students were given the chance to ask anything that they were not sure about before they signed the consent form prior to take part in the study. Pseudonyms were used for all participants to maintain anonymity and confidentiality. As explained in the participant information sheet (PIS), participants had the right to withdraw from the project at any time they wished without the need for an explanation and that all data collected would be kept confidential and anonymous. All of ethical concerns had been addressed to ensure that there were no conflicts of interest that might threat the "validity" (Atkins and Wallace, 2012) or "credibility" (Corbin and Strauss, 2008) of the research.

3.7.1. Ethics approval

Ethics approval for this study was obtained from the University of Leicester Ethics Review Panel.

Chapter 4 - Addressing misconceptions about meiosis using video

> "*Those lucky genetics students on the distant planet Zork! On Zork, most organisms are diploid, and genes work more or less like they do on Earth, but meiosis is much simpler. There is no pre-meiotic S phase of DNA replication, so there is no chromatid formation. The homologous chromosomes simply pair, engage in crossing over at the two-strand stage, and then segregate into two daughter cells. Therefore, all the processes achieved on Earth are achieved on Zork, but with only one meiotic division. On Zork the genetics students never have a problem with meiosis-in fact they consider it trivial and go on to more challenging stuff*."
>
> (Griffiths and Mayer-Smith, 2000)

Overview

In this chapter the development of an educational video resource illustrating meiosis and the evaluation of its impact in assisting undergraduate students to gaining a better understanding of the concept of meiosis is discussed. From here onwards, throughout this thesis, this animated video illustrating meiosis will also be referred to as the ***'meiosis video'***. Firstly, common misconceptions about meiosis is examined, followed by a section of methods dedicated to explaining a detailed approach in addressing research questions related to the development of the educational video. The next parts include the development and evaluation of the video using groups of Indonesian students reflecting an action research approach. A comparison with counterpart group of UK students in the second cycle of action research gives an insight of the effectiveness of video in two different educational contexts. This chapter is concluded with the reflection and recommendations in using the meiosis video.

4.1. Problems in understanding meiosis

Meiosis is a crucial, yet difficult to understand concept for students at various levels of education, including at the undergraduate level (Brown, 1990; Dikmenli, 2010; Kindfield, 1994; Quinn, Pegg and Panizzon, 2009). In genetics, meiosis is fundamental to inheritance, and in developing an understanding of how genetic information is transmitted from an organism to its offspring (Klug *et al*, 2016), although an understanding of meiosis is not always related to the ability of many students to solve problems in Mendelian genetics (Kindfield, 1994). Meiosis is characterised by three principles, (1) it involves a single chromosomal duplication which followed by two consecutive nuclear divisions (2) it produces four daughter cells (also called gametes), each containing one set of chromosomes (haploid), one member from each chromosome pair from the diploid parental cell, and (3) it contributes to the generation of variation of the offspring through two events, crossing-over and the random assortment of chromosomes (Hochwagen, 2008; King, Mulligan and Stansfield, 2013; Klug *et al*,

2016; Hartl, 2014; Brown, 2012; Raven and Johnson, 2002). A more detailed description of the principles of meiosis is discussed in Chapter 2.

Griffiths and Mayer-Smith (2000) emphasised the significant problems students face when they deal with meiosis. Some of the problems are due to having a misrepresentation of the structures involved (chromatid and homologous chromosomes) and mistakenly considering daughter cells of mitosis as gametes. Lai (1996, quoted in (Griffiths and Mayer-Smith, 2000) explained some prominent misunderstandings amongst undergraduate students. Those were (1) the dominant alleles are segregated together, (2) there is chromosome replication but no pairing, which results in the confusion about the product of mitosis, (3) one cell division in meiosis (chromosomes pairing without replication, (4) a changing-partner of non-sister chromatids (pairing up with their non-sisters). All misunderstandings lead to the peculiar explanation of meiosis which Griffiths and Meyer-Smith described above as the meiosis on "Zork" (see vignette).

Problems in understanding meiosis centred on the complexity of its subordinate or subsequent concepts, i.e. the fundamental concepts of cell and chromosomes (Smith, 1991). Various studies related to the exploration of problems in understanding meiosis revealed that the misunderstandings of meiosis mostly fall within two categories. The basic problem comes from the inability to recognise and to distinguish between the structure of chromosome, chromatid, and homologous pair (Lewis, Leach and Wood-Robinson, 2000b; Tsui and Treagust, 2007). This problem is complicated by another issue commonly faced by high school or college students, the concept of ploidy and the relation between genes, DNA and chromosomes (Kindfield, 1994; Mills Shaw *et al*, 2008; Lewis and Wood-Robinson, 2000). The most prominent problems in learning meiosis involved the incorrect perception of meiosis as a series of separate stages. The latter happened because students mainly focused their effort to memorise stages of meiosis rather than to discern what happen in each stage (Smith, 1991). Typical learning resources which portray the still images of stages in meiosis, such as those represented in textbooks, exacerbated the visualisation of meiosis as a number of stages, rather than as a comprehensive event of cell division. A compilation of various misconceptions regarding meiosis has been addressed in the questions of the meiosis concept inventory (MCI) test developed by (Kalas *et al*, 2013). In general, they pinpointed three areas of where common misunderstandings are identified in understanding meiosis. The further

detail of each type of common misconceptions in understanding meiosis is presented in Table 4.1.

Table 4. 1 Three types of common misunderstandings of meiosis adapted from (Kalas *et al*, 2013)

Common misunderstandings of meiosis		
Chromosome structure (Type 1)	**Time of events (Type 2)**	**Ploidy (Type 3)**
Considering homologous chromosomes as sister chromatids	Thinking that DNA replication occurs at prophase 1, and this event doubles the chromosome number	Having the idea that ploidy is related to the number of chromosomes (rather than as sets of chromosomes)
Having the incorrect idea of alleles and locus on the chromosomes	Having the idea of chromosomes splitting into two cells at metaphase or anaphase	Having the idea that ploidy is related to a certain shape of chromosomes (e.g. depicted diploid as a duplicated chromosome)
Having the incorrect idea of the relation between chromosomes and DNA (e.g. one chromosome consists of one DNA double helix)	Having the idea that only one major event marks each stage (e.g. either homologous pairing or crossing over occurs at prophase)	

4.2. The rationale for developing an educational video of meiosis

Meiosis is discussed repeatedly in any biology curriculum at secondary school, college and university level. It is therefore not surprising that numerous resources have been developed to teach this particular concept. Wright & Newman (2011) reported more than 6,000 resources in various formats of worksheet, simulation, and model. Despite this myriad of available resources to teach meiosis, students' misunderstandings of meiosis have persisted over decades (e.g. (Ozcan, Yildirim and Ozgur, 2012; Rodríguez Gil, Fradkin and Castañeda-Sortibrán, 2018).

Most of the teaching interventions created for tackling problems in meiosis had been developed to address specific sub-concepts. In other words, each learning resource has its purpose to induce a change of concept in focus. Luo (2012), for example, had developed a model of spindle fibres using a double spring model to emphasise the force that enable fibres to pull chromosomes from the centre of the cell (in metaphase) to the poles (during anaphase). Kindfield (1994) developed the problem set which focuses on helping students to visualise chromosomes behaviour by asking them to label alleles on chromosomes at the various stages of meiosis, including gametes. Other resources were specifically targeted to teach the concept of ploidy by emphasising homologous

chromosomes using matching-socks (Chinnici, Neth and Sherman, 2006) and by creating an interactive lesson whereby students were asked to identify ploidy in each stage of meiosis (Wright and Newman, 2011). Many meiosis teaching aids are focused on helping students to visualise chromosomal behaviour by asking students to manipulate models of chromosomes undergoing each stage of meiosis (Mickle, 1990; Clark and Mathis, 2000; Locke and McDermid, 2005).

The visualisation of chromosomes movement during meiosis is perhaps the most important point for promoting the understanding of the concept. It is imperative that students learn meiosis by observing the movement of chromosomes. Many textbooks present the stages of meiosis as still-frames of the event which are thought to lead students to focus on memorising the name of the phases, rather than focusing on what happens in the whole process of meiosis (Smith, Michelle K., Wood and Knight, 2008). The use of video rather than still-pictures would have the advantage of showing meiosis as a complete process. As the content-delivery tools in learning, videos could attract students' attention and have the advantage of illustrating the abstract concepts (Brame, 2016). Video has been widely known as a learning tool as part of traditional courses in higher education, therefore it should be easy to introduce the video to the class. By using a video, the imperative idea of presenting the way chromosomes are pairing and separating, illustrated as the "meiotic ballet" (Page and Hawley, 2003) would be feasible.

There are teaching videos which show the real event of meiosis (e.g.WEHImovies, 2017). However, this video has a limitation of showing only a simple representation of meiosis. Complex concepts of meiosis, such as variety of genes/alleles indicating the genetic diversity of the daughter cells produced and the random attachment of opposite spindle fibres to each chromosome of a pair (meiosis 1) or to each sister chromatid of a chromosome (meiosis 2) are not shown in this video. To promote students' understanding of meiosis as a concept, all subsequent concepts and events regarding meiosis should be taught simultaneously. For this purpose, a video depicted the analogy model of chromosomes will be better-suited. An analogy enables the simplification of the concept and principles of meiosis presented in the video, whilst at the same time allowing students to follow the process of meiosis in a continuous manner. Moreover, video meets the aim of presenting the correct conceptions of the common misunderstandings of meiosis found globally amongst students.

4.3. Specific Methods for the development of the meiosis video

Here the development refers to the whole process of design and evaluation of the meiosis video. The general methods in developing the educational video followed the sequence of action research in developing targeted educational resources (see Chapter 3 section 3.1). Aspects discussed in this section are limited to the detail of procedure which was adopted specific to developing the video.

4.3.1. Mapping research questions with methods

The study of the development of the meiosis video aims to address four specific research questions. The four questions for the project described in this chapter were derived from the research questions for this thesis (Chapter 1, section 1.3) and the methods were mapped to these specific questions (Table 4.2). The use of two or more data sources showed the data triangulation method.

Table 4. 2 Mapping research questions with types of data used to study the effectiveness of the meiosis video

Research questions	Source of data			
	MCI Test	Observation	Interview	Researcher journal
RQ 1. How is information regarding common misconceptions used to develop the meiosis video?				√
RQ 2. What are university students' existing perceptions of the basic concepts of meiosis?	√			
RQ 3. In what ways does the meiosis video modify university students' misconceptions of meiosis?				
RQ 3.1. What misconceptions are altered after use of meiosis video?	√		√	
RQ 3.2. What elements of meiosis video contribute to the change?		√	√	√
RQ 3.3. How do university students perceive their learning experience with the meiosis video?		√	√	
RQ 4. Are there any differences in the way university students in Indonesia and the United Kingdom perceive the benefits of meiosis video?	√	√	√	

4.3.2. Research flow and timeline

The procedure for developing the educational video followed the general methods for developing targeted resources (Chapter 3, section 3.2). The research flow for this project outlines in detail the stages for evaluation of meiosis video between the case

with Indonesian and UK students (Figure 4.1). The project timeline shows the time dedicated to each stage in the developing procedure of the educational video (Figure 4.2). The development of the video was completed within a period of two years, starting from the initial idea until the last data collection with students in the UK case. Most of the time was dedicated to design and develop initial content of the video and the waiting time for the appropriate point in the students' courses (module) to do the trial. The timetable for collecting data with students regards to the evaluation of the video is given in Table 4.3.

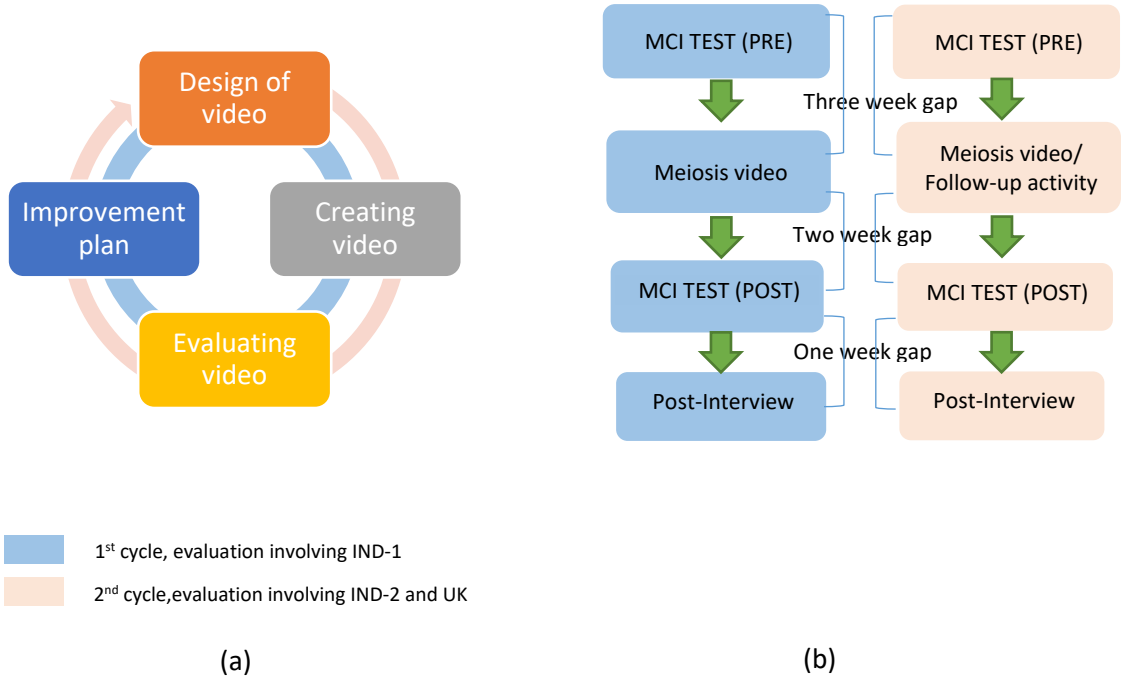


Figure 4. 1 A flow of diagram illustrating the development of the meiosis video. *(a) The evaluation stage in the first cycle (blue ring) involved a group of Indonesian students (IND-1), whilst the same stage in the second cycle (pastel ring) involved group of Indonesian students (IND-2) and a group of UK students (UK) (b) a flow of the evaluation stage for each cohort showing the activity they did related to the method of data collection (test, observation, and interview)*

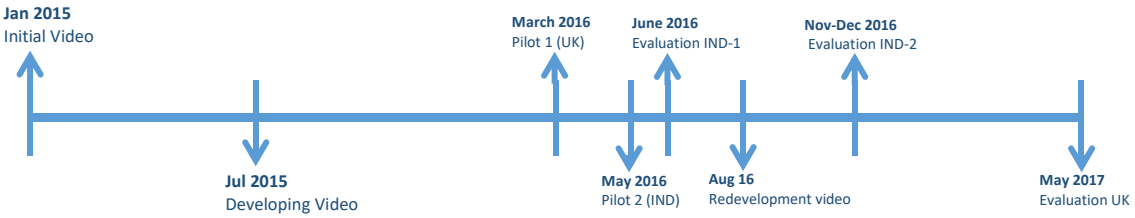


Figure 4. 2 Research timeline showing significant events in the development of the meiosis video

Table 4. 3 Data collection timetable for the evaluation of the meiosis video

Stage	Date	Activities
1st	**INDONESIA FIRST COHORT (IND-1)**	
	10 May 16	MCI Test (PRE)
	09 Jun 16	Teaching session/observation to students' interaction with the video
	14 Jun 16	MCI Test (POST)
	20-22 Jun 16	Interview
2nd	**INDONESIA SECOND COHORT (IND-2)**	
	15 Nov 16	MCI Test (PRE)
	06 Dec 16	Teaching session/observation to students' interaction with the video
	14 Dec 16	MCI Test (POST)
	16-20 Dec 16	Interview
	UK	
	03 May 17	Teaching session/observation to students' interaction with the video
	03 May 17	MCI Test (POST)
	02 Jun 17	Interview

4.3.3. The context of study and participants

The development of the meiosis video followed the action research procedure (see Figure 4.1), with the researcher designing and creating the meiosis video. At these two stages (design and create), data were collected as the description of stages recorded on the manuscript (journal of developing resource). At the resource evaluation stage, data were collected through various sources to study how students get benefit from the video and how they perceive learning meiosis with the video. At the final stage, the researcher reflected on the three previous stages (design, create, and evaluate) to consider the effectiveness of educational video in addressing misconceptions of meiosis as well as to recommend an improvement of resource.

The evaluation stage involved three groups of students, two group of Indonesian students (IND-1 and IND-2) and another group of UK student (UK) (see Chapter 3 section 3.3 for detail characteristic of participants). The participating students had a completed genetics module (IND-1) or were in the process of completing it (IND-2, UK). Table 4.4 shows the number of students involved for each group.

Students were invited to have an informal teaching session with the meiosis video. The MCI test was given to participants before (pre-test) and after (post-test) the teaching session to measure the impact of the video in addressing students' misconceptions. Students' interaction with the resource was observed during the session and recorded as a notes. Within a week of the session, students were interviewed about their understanding of meiosis and their learning experience using the video. Only students who had gone through all the evaluation stages (test-try out-test-interview) are regarded as participants, due to the requirement to triangulate the data.

In the case with Indonesian students (IND-1 and IND-2), the MCI test (pre-test) was given to all students taking the genetics module at the time the study was conducted. This is done to illustrate general students' understanding of meiosis for those two cohorts. The total number of students taking the MCI test in the two cases was shown on Table 4.4.

Table 4. 4 Number of participants involved in the evaluation stages of the meiosis video

Case	*Academic year*	*Number of students taking MCI test*	*Number of students consent to participate*	*Number of participants*
IND-1	***2015/2016***	***66***	***28***	***17***
IND-2	***2016/2017***	***78***	***25***	***19***
UK	***2016/2017***	***-***	***2***	***2***

4.3.4. Data collection, analysis and interpretation

In general, the data collection, analysis and interpretation for this project followed the thesis methods in collecting and analysis data described in Chapter 3 section 3.5 and 3.6. This section is dedicated to give a more detail explanation to specific data collection and analysis relating to the specific testing and interviews used to evaluate this resource. Other methods of data collection and analysis which was not described in this section followed the general procedure for thesis.

Data collection

The Meiosis Concept Inventory (MCI) is a validated test which is designed to examine students' understanding of meiosis, as well as to identify students' common alternative conceptions (misconceptions) of meiosis (Kalas *et al*, 2013). The author developed the test with an intention:

> "*… to investigate students' understanding of the subconcepts of ploidy; relationships among amount of DNA, chromosome number, and ploidy; timing of major events during meiosis; and pictorial representation of chromosomes (e.g.,sister chromatids vs. homologous chromosomes, general arrangement of chromosomes at metaphase of meiosis I vs. meiosis II)*" (Kalas *et al.*, 2013) p.656.

The MCI is comprised of 17 questions of multiple-choice or multiple-true-false format. Table 4.5 shows a summary of topics for each question item derived from MCI

Table 4. 5 A summary of question item analysis of Meiosis CI. Questions were grouped based on the Concepts Tested adopted from characteristic of Meiosis CI (Kalas et.al, 2013). *Question topics and possible identified misconception derived from the test were explained through analysis of each question (and each option for the latter) with a guidance from Meiosis Concept Inventory Questions Explanation of Misconceptions package given by test developer. The asterisk (*) shows the items which ask students to choose one correct option (multiple-choice format). The rest of questions asked students to choose possible correct options (multiple-true-false format)*

No	Concepts Tested[K]	Topic of question	Possible identified misconceptions derived from the test
1*	**A** (Ploidy; differences between chromosomes, chromatids, and homologous pairs; +indicates question concerning what counts as chromosome (see also concept C); ^ indicates questions concerning chromosomal representation of genotypes (see also concept F)	The definition of haploid	(1) "Ploidy" is associated with the number of chromosome or (2) with the chromosome structure
2*		Pictorial representation of diploid cell at G1 phase[+]	(1) A chromosome is indicated by its duplicated structure; (2) a diploid cell is indicated by the duplicated structure of chromosome; (3) DNA replication doubles the number of chromosomes
3*		The triploid cell notation	(1) a duplicated chromosome symbolises diploid cell; (2) considering chromatids as chromosomes; (3) different ideas to what consider as one set of chromosomes
4		Pictorial representation of haploid	(1) Haploid means the chromosomes are in unduplicated structure; and or (2) having the uneven number of chromosomes
5		Pictorial representation of diploid	(1) Diploid means the chromosomes are in duplicated structure; and or (2) having the even number of chromosomes
6		Pictorial representation of somatic cell, AaBbDd)[^]	(1) somatic cells are diploid thus the chromosomes are in duplicated form; (2) all dominant or all recessive alleles are located in one chromatid; (3) DNA replication increases the number of chromosomes
7	**B** (Relationships between chromosomes, DNA, and chromatids, and relation to DNA replication)	What a replicated chromosome ("X") symbolises	(1) A confusion between sister chromatids and homologs; (2) a duplicated chromosome symbolises diploid cell
8		Consequences of DNA replication to DNA, chromosomes, and ploidy	(1) Thinking that replication will increase the number of chromosomes; (2) and/or the ploidy (the number of "n")
9		The representation of DNA molecule in "X"	(1) a chromatid contains one ssDNA molecule; and or (2) a chromosome contains one dsDNA molecule; (3) DNA molecules in a chromosome are not in double-stranded structure
10		Identifying cells with the same number of dsDNA	(1) the number of dsDNA molecules before and after DNA replication is the same
11	**C** (what "counts" as a chromosome)	Identifying cells with certain number of chromosomes	(1) Counting a chromatid as a chromosome; (2) A chromosome is indicated by its duplicated structure
12*		Counting the number of chromosomes of a cell	(1) Counting a chromatid as a chromosome; (2) Counting a homologous pair as a chromosome

13*	**D** (Timing of events during meiosis)	Determining stages of meiosis where cell has the same number molecules of DNA as its somatic cell before replication	(1) DNA replication occurred at prophase 1; (2) cell segregation occurred at metaphase 1; (3) gametes have the same amount of DNA with somatic cell
14		Determining events in prophase 1	(1) Only one major event marking one stage of meiosis; (2) A lining up of homologous pair occurred during prophase; (3) DNA replication occurred at prophase 1
15*	**E** (Segregation, chromosome arrangements, and consequences of crossing over)	Identifying the meiosis stage which represent the consequence of crossing over	(1) A confusion between mitosis and meiosis; (2) a confusion between events in meiosis 1 and 2; (3) could not predict the outcome of crossing over
16*		Identifying the meiosis stage which represent homologous pairing	(1) A confusion between events of mitosis and meiosis, (2) A confusion between events of meiosis 1 and 2
17	**F** (Gamete formation; chromosomal representation of genotypes)	Pictorial representation of gametes produced by parental cell of AaRr	(1) gametes are haploid thus the chromosomes are in unduplicated form; (2) all dominant or all recessive alleles are inherited together; (3) gametes have the same chromosome arrangement as the daughter cells of mitosis

MCI test was distributed as a paper and pencil test for this project. This differed from the recommendations of the author to present the test using power point. This alternative step was chosen following considering of the location of study (Indonesia) where LCD projectors commonly project onto the wall (not on a screen) which may reduce the quality of its projecting image. Another factor was the possibility of a sudden power cut, which commonly occur in the location. Anticipating these conditions that may distract students while they were conducting the test, the MCI was distributed as paper and pencil test.

Though the format was presented differently, the tests were given to Indonesian and UK students for the exact same duration (17 minutes). All question booklets were collected back and destroyed after the post-test to ensure the confidentiality of the test, as requested by the test developer. Whilst doing the test, students were asked to present their names on the answer sheet. This was important due to the need to compare students' answers before and after the teaching session with the video. However, no name of students participating in this project is presented in this thesis. Instead, students are given the pseudonyms to ensure their confidentiality (see section 3.7, ethics).

The interview was designed to be conducted within a week of the teaching session with the resource. However, in the UK case, it was conducted about a month later due to students' preparation for final module exam. Students' understanding of meiosis was elicited through the discussion of pictures showing illustration of a cell in different phases of meiosis. Models of chromosome on the pictures were the same as models of chromosome in the video.

Data analysis

Students' answers were marked using keys provided on the "Meiosis Concept Inventory Questions Explanation of Misconceptions" given by the test developer. An overview to the level of overall students' understanding of meiosis was obtained by counting the percentage of correct responses for each item of MCI for the total student population taking genetics module in each cohort (IND-1 and IND-2). IND-1 and IND-2 cohort responses to MCI before (pre-test) and after (post-test) were marked using the same keys. For each question, individual students' responses to MCI before and after are compared to reveal whether students gave: (1) remaining correct, (2) remaining incorrect, (3) change to correct, or (4) change to incorrect answer.

The possible identified misconceptions derived from their answers (see Table 4.5 column 4) were analysed. The interpretation of students' revision of misconception in meiosis from analysis of the MCI test was validated through triangulation of data from students' interview responses.

4.4. The design and creation of the meiosis video

This section discusses the initial design and construction of the video. The design stage focused on determining the instructional purpose of the video, analysing common misconceptions which informed the content of the video, and scheming the presentation of the video. The construction stage centred on producing the video based on the script.

4.4.1. The design of the meiosis video

The designing procedure of the video was based on the suggestion of making the instructional material formulated by Gagné (Gagné *et al*., 2005) (Figure 4.3).

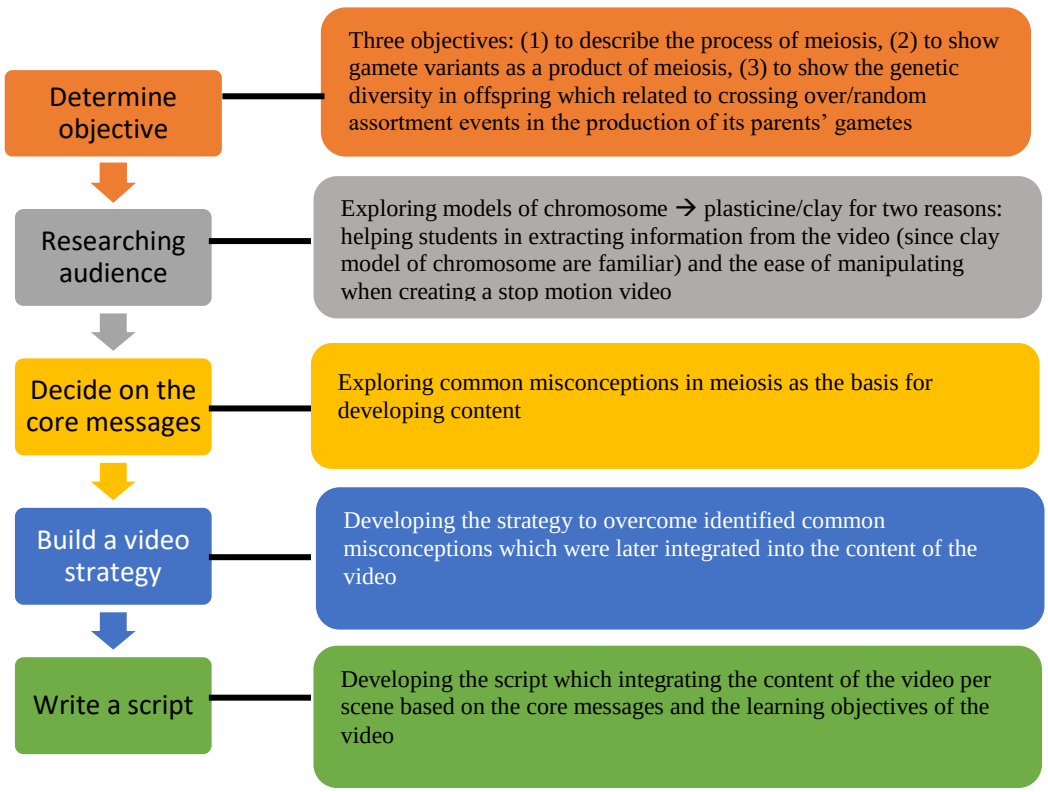


Figure 4. 3 Steps in the design of the meiosis video. *The right-hand blocks show the specific event related to each stage.*

Following the steps in creating instructional media, the design of the video began with determining its purpose. Reflecting the three principles of meiosis posited by

(Hochwagen, 2008), this resource aims to (1) depict the process of meiosis, the two consecutive nuclear divisions following the chromosome duplication, (2) show the haploid-gamete produced by the process, and (3) and the generation of genetic variation of the offspring through crossing over and independent assortment. The comprehensive concept of meiosis in the video was expected to help undergraduate students to get the complete understanding of meiosis.

The initial step was then followed continued by finding a suitable chromosome model to show the three main concepts of meiosis. This was done through two steps, exploring chromosome models via the google search engine and reading selected articles which focused on modelling chromosome in their instruction. Typing "chromosome model" into the google search function produced 48,000,000 results. Scanning through the results, suggested that in general there were two models of chromosome-digital model (2D and 3D), and the physical model, which were made from various materials (e.g pop beads, pipe-cleaner, magnet, clay). Due to the resource and skill limitation in creating a digital model of chromosome, it was decided to explore the approach of making a physical-analogue model of chromosome.

The use of simple analogue model in teaching meiosis for college and university students was shown in several papers. Locke and McDermid (2005) used the "pool noodles", a type of foam stick to aid someone floating in a swimming pool, to help second-year undergraduate students simulate meiosis, as well as recognising the homologous chromosome (which was presented as different colours). Luo (2012) adopted the double spring to demonstrate to college students the logical representation of the work of fibres in pulling chromosome during cell division. Clark and Mathis (2000) used a simple material of chenille stern, coloured yarn plastic, straw, and containers to simulate meiosis for undergraduate students at Middle Tennessee State University. Rindos and Atkinson (1990) created the pizza chromosome activity to move students beyond the concept of one gene, one phenotypic (trait). All in all, this literature suggests that simple analogue material could be useful to modelling chromosomes amongst undergraduate students.

Following consideration of all factors above, plasticine/clay became the choice for modelling chromosome for this educational video. Students are often familiar with chromosome model made by clay, as google search engine showed 8,200 sources for "meiosis Claymation", which are mostly created by students. The familiarity to the model/material will reduce the time required to familiarise to the model (representation)

and enhance students' in getting the message through increasing their representational competencies (Rau, 2017). Using clay also has the advantage of the ease of use of material to reproduce a stop-motion video.

The next stage was to consider the message of the video. This resource was developed to improve students understanding by overcoming their misconceptions. Common misconceptions of meiosis were used as basis for developing strategy to tackle this. Various misconceptions in meiosis had been crystallised by Kalas *et al*, (2013). In this case the key points of misconception of meiosis (Table 4.1.) became the guidelines in designing the content of the video. A summary of the strategy in overcoming misconceptions of meiosis based on information on the common misconceptions were presented on Table 4.6.

Table 4. 6 A summary of the strategy of presenting concepts in the meiosis video to address common misconceptions. *Common misconceptions of meiosis were derived from the three types of common misunderstandings adapted from Kalas et al., (2013). These strategies to address misconceptions are later integrated into the content of the video*

No	Common misconceptions of meiosis	Strategy to address misconception
1	Considering homologous chromosomes as sister chromatids	Use two colours of clay to represent maternal-paternal chromosomes. A pair of different colours is the homologous chromosome, a pair of the same colour is the sister chromatids
2	Incorrect idea of alleles and locus on the chromosomes	Some alleles will be presented as different big/little letters on the homologous chromosomes
3	Incorrect idea of relation between chromosomes-DNA: one chromosome consists of one DNA double helix	To give a representation of DNA which assumed to condense and turned to single chromosome (in the beginning of the video)
4	Considering DNA replication occurs at prophase 1 which doubled the chromosome number	To present a diagram of cell cycle showing replication (duplication) occurs during S-phase. It was given before covering prophase meiosis 1 to emphasise the event does not occur at prophase 1.
5	Having the idea of chromosomes split into two cells at metaphase or anaphase	Giving the representation of cell boundary during metaphase and anaphase to show that chromosomes are on the same cell during those phases.
6	Having the idea of only one major occasion remarked each stage (e.g. either homologous pairing or crossing over occurred at prophase)	To give the cue (label) of event during each phase (in different colour) to mark the length of each phase. This would be useful to show the continuous process during phases in meiosis To show the crossing over occur at Prophase 1 which produce a chiasma because they did not separate until anaphase. This structure is for the stability of homologous pairing which enable meiosis to perform
7	Having a conception that ploidy is related to the number of chromosomes (rather than as sets of chromosomes)	To show a haploid cell (unpaired chromosome), then show the same cell in diploid (paired chromosome with the appearance of homologous chromosome). Number of chromosome were given as cue (label)
8	Having a conception that ploidy is related to a certain shape of chromosomes (e.g. depicted diploid as a duplicated chromosome)	

The script of the video was written to conceptualise both content and presentation. This acted as the scheme for creating the resource. The video has three important objectives to cover, to show the meiosis process, to show the gametes (product of meiosis) and to show how meiosis generates genetic variation. The three objectives were presented as one comprehensive story in the video. To do so, the story begins with showing the meiosis process which results in gamete variations. The fertilisation (mating) brings together gametes from two individual generating genetic variations in the offspring (next generation). Strategies to address misconceptions were integrated into the content of the video. To make sure that the content was presenting subordinate (supporting) concepts correctly, each stage of content development was confirmed with three genetics textbooks (Brown, 1992; Hartl and Jones, 2005; Pierce, 2010). In the end, as the video contains many terms, a dedicated section covering the explanation subordinate concepts was added. The flow of the story in the meiosis video is presented in Figure 4.4.

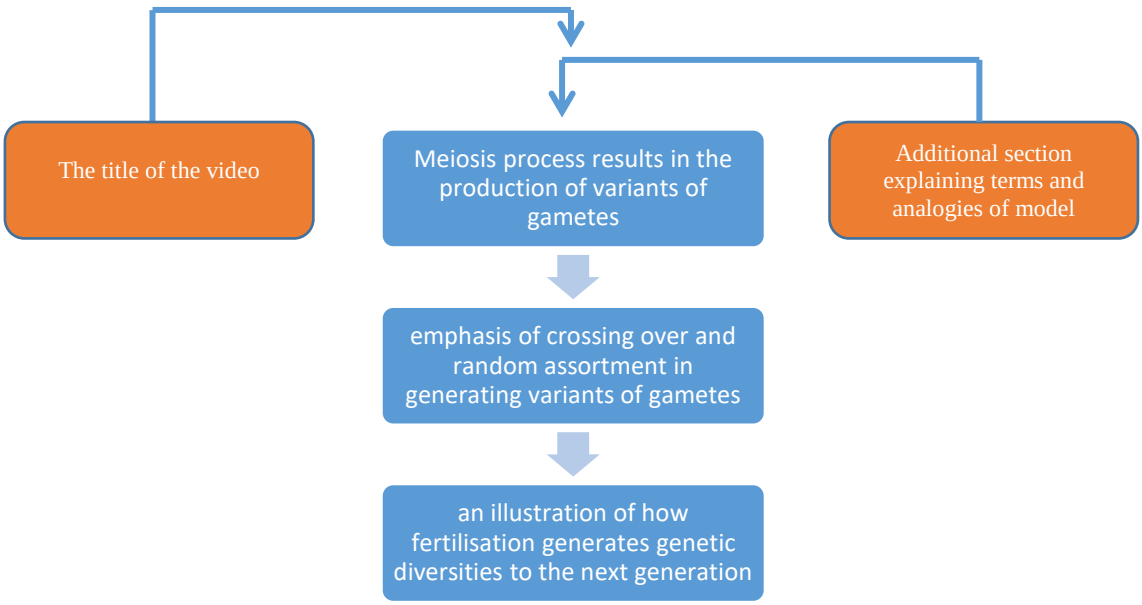


Figure 4. 4 Storyline for the meiosis video with chromosome model made of plasticine. *Three main parts of the story was shown as blue boxes. The three events run in sequential manner. An additional section explaining the terms and analogies used in the video was integrated after the construction of the main parts. The last stage was giving the video title*

4.4.2. The construction stage and pilot study

The video was constructed as directed by the script. The initial step was to make the physical model of the chromosome (made of plasticine), the spindle fibre (made of

wire), and a model of cell (displayed as a round line). The chromosome model was made in two colours to represent paternal (father-line) and maternal (mother-line) chromosomes. Since it represents the fertilisation between two individuals, the chromosome model was prepared in four different colours, two colours for each individual. It was initially planned to illustrate meiosis using three pairs of chromosomes, which would be different from the common depiction of two chromosomes in the textbooks (e.g. (Klug *et al*, 2016; Brown, 1992). However, there was not enough space to project the movement of all chromosomes, so eventually, only two pairs of chromosomes were used.

A stop motion technique was applied to make an animation (movement) of the model of the chromosomes. Stop motion is "*an animated-film making technique in which objects are physically manipulated in small increments between individually photographed frames so that they will appear to exhibit independent motion when the series of frames is played back as a fast sequence*" (Wikipedia, 2019). It can be constructed by recording the object with stop motion software, such as I-stop motion. With the same increments, using larger number of frames per second makes the object move very fast when it played.

The construction of the video was through a trial-and-error process. The initial version of the video contained only the first main part of the storyline and it only recorded meiosis of one individual (two-colour chromosome model). The recording was carried out at the GENIE-CETL (Genetics Education Networking for Innovation and Excellence-Centre for Teaching and Learning), University of Leicester using a DC camera which with software Istop-motion version 2. The model of chromosome was moved one step at a time, when each movement was captured. The stop-motion recording was done using the default 12 frames per second on Istop-motion. Editing of the video was conducted using Moviemaker software ver.11. The result showed that the chromosome movement was not very smooth, which made the chromosome movement unnatural. Several short trials recording the animation using different frames were made until the most convenient way of recording producing smooth movement of chromosome was found. The trial-by-error procedure was one of the reasons for the long-time span in creating the resource. An example of the recording is shown on figure 4.5.a.

The experience in the making of version1 led to the adoption of better technical recording set-up for the construction of second version of the meiosis video. The objects

was recorded in the same location and using the same devices. The only difference was with the editing software, where Movavi video editor 10 was used.

As with the first version, the recording was conducted at the GENIE-CETL, University of Leicester using DC camcorder series AG-DVXICOBE and software Istop-motion version 2. The model of chromosome was moved one step at a time, when each movement was captured. The stop-motion recording was conducted at 10 frames per second. Narration was recorded separately using common voice recorder which was inserted to the video in the editing process. The movie editor was changed to Movavi video editor ver.10. Additionally, in this version, there were parts which showed still pictures between two motion pictures to highlight important concepts. The concept in focus was accompanied with a visual cue (e.g. text that explain which one is which) to increase the concept retention (Tabbers, Martens and Merriënboer, 2004). Finally, video was made in two language versions, English and Indonesia (Appendix B-1, B-2). See Figure 4.5.b for an example of the recording.

(a) **(b)**

Figure 4. 5 An example of a one frame-photograph between (a) meiosis video ver.1 and (b) meiosis video ver.2

Piloting of the video was done with several groups. First, it was shown to four members of the GENIE-CETL, University of Leicester, who taught on Genetics module and have an experience in developing learning resources. They suggested making the video available in two versions, the complete version and the partial one. Due to the

long duration of the complete video (± 20 minutes), presenting them as three separate videos would be valuable. These two versions of video were made prior to the next pilot study.

The video was then piloted with students at the University of Leicester. Ten Medical Genetics students, who had taken Genetics module in the previous semester, participated in the pilot study. Due to the time limitations, face-to-face interview could not be conducted. Thus, to piloting interview instrument (the pictures to elicit the discussion of concept understanding), the pictures were transformed into a simple test called MCT. Also, students were given questioner containing the questions in the interview to measure their perception of the educational video, including finding out whether they have seen all important concepts intended to show on the video. In general, majority of students gave positive feedback over video (Figure 4.6). They could also identify important concepts in the video, particularly recognising sister chromatids. Students gave a good feedback on the video of meiosis, which showed by the higher percentage of agreement on the positive sides of the video (enjoyment, clarity and the helping aspect of the video to their understanding of meiosis). Students gave a feedback on the end of the session as summarised on Table 4.7. Only suggestion to checking the corresponding between narration and visualisation was conducted. All other suggestions involved a considerable time to change the video which was not feasible due to limited time before the actual trial of the video.

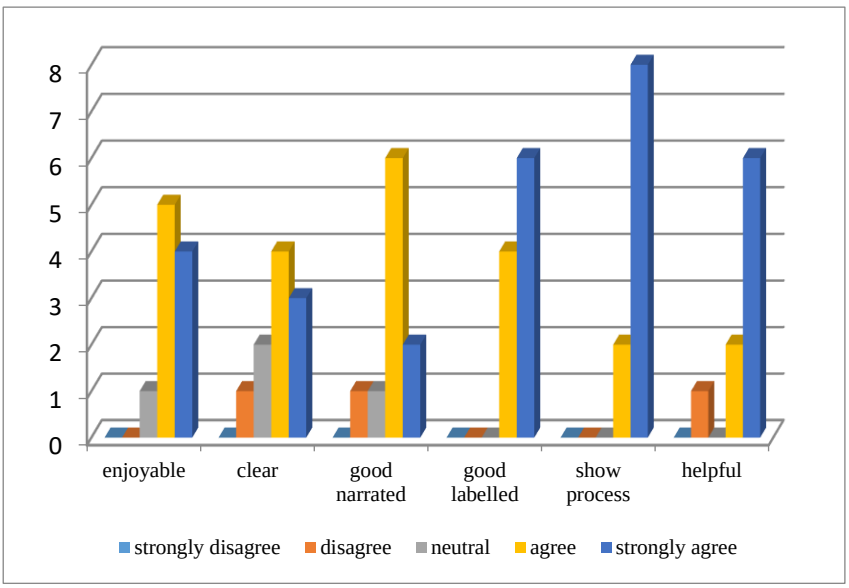


Figure 4. 6 University of Leicester Medical Genetics students' perception on pilot project of meiosis video (n=10). *Questions were presented as questionnaire. Students were asked to evaluate several aspects of the video (horizontal axis) based on five-scale of measurement.*

Table 4. 7 A summary of students' comments on pilot project of meiosis video (n=10). *Number in the brackets referred to the number of students with the same idea*

Most useful parts	Showing chromosome movement in the meiosis process [6] Explaining the related terms in meiosis [2] Explaining crossing over and random assortment [1] Explaining through labelling and narration [1]
Least useful parts	Narration is not clear or disappeared [2] Simulation of meiosis in family seemed to be abruptly ended [1] Showing gametes repetitively [1]
Suggestions	More time forthe introduction part [1] Add written definition whenever needed [4] Reduce the animation speed [2] Do not need to use the "transition animation" all the time [1] Matching between sound and visualisation (at some parts) [3]

Another pilot study was conducted with a group of Indonesian students. Participants (seven) were students of the Biology teacher education programme at Universitas Tanjungpura, who had taken Genetics module in the previous semester. The focus of the pilot was to try running a complete video (in Indonesian language) and test research instruments. No technical problems were found in playing the video. Pictures could stimulate students when to talk about their concepts of meiosis, thus the picture is a suitable instrument as an elicitation technique in an interview.

4.5. Evaluation of impact of the meiosis video on students' understanding: IND-1

This first case with students in Indonesia was originally conceptualised as a pilot study. The students that took part on this first evaluation were used because they matched with the target criteria. Due to the enthusiasm of the participants, this resulted in a rich set of data. It was decided that this case would not be a pilot study in the beginning of data collection. This is possible in qualitative research as it is "emergent, and flexible, responsive to changing conditions of the study in progress" (Merriam, 2009) (p.8). For this particular cohort (Indonesian first case, IND-1), data were collected following the methods as explained in section 4.3, ensuring that there would not be any adverse technical faults to consider as this was the first cycle trialling meiosis video.

4.5.1. The existing understanding of meiosis among Biology education students of IND-1 cohort

Students' (IND-1) understanding of meiosis was measured by analysing their responses to the MCI test and to the questions during the interview.

To investigate general understanding of meiosis to the students' population where the IND-1 case was embedded, the MCI test was given to the total number of biology education students (66) who had taken and passed Genetics module in the previous semester. Proportion of students' correct responses to each MCI question was presented on Figure 4.7. Students' incorrect responses were analysed to find options chosen for each incorrect answer. The largest percentage of students choosing an option (for multiple choice type) or certain combination of options (for multiple true false) showed the common misconceptions held by this cohort. A summary of findings is presented on Table 4.8.

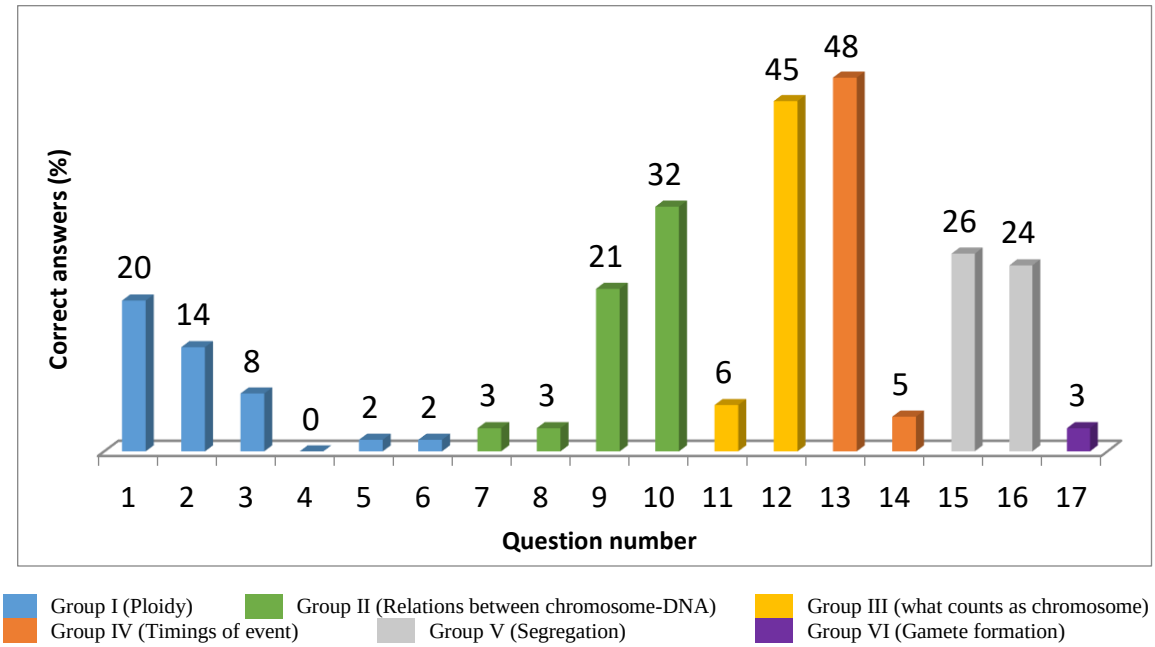


Figure 4. 7 Proportion of correct responses to MCI test given by Year 3 Biology Education students at Universitas Tanjungpura in the academic year of 2015/2016 (n=66). *MCI test was given to investigate the understanding of meiosis concept to the general population of students who had taken genetics module in the previous semester. Colour on the diagram showed the division of the group of MCI questions*.

Figure 4.7 showed students have a low understanding to the meiosis concepts although they had completed their genetics module. Less than 10% students responded correctly to seven questions (item number 3, 5, 6, 7, 8, 11, 14, and 17). None of students gave correct answer for question number 4. Students gave better responses to other number of questions. Yet, only less than a half number of students gave the correct answers. Students' difficulties in answering question of MCI did not concentrate on

particular group of questions but comprises different areas of important subordinate concepts of meiosis.

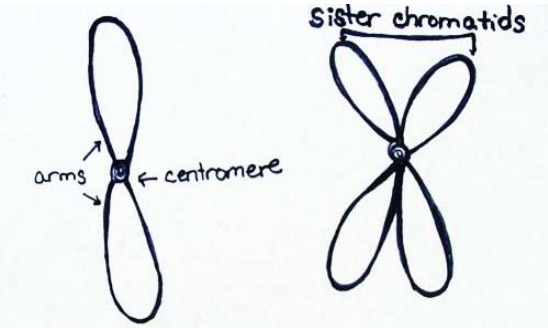


Figure 4. 8 Model of chromosome: an unduplicated (left) and a duplicated form (right). *Many students mistakenly consider the left structure as haploid, while the right as diploid. Both structures are counted as one chromosome*

Table 4.8 showed the possible explanation for the low correct responses to MCI test given by this group of Indonesian students. Four questions with lower correct responses (number 3, 4, 5, and 6) were related to identify ploidy of cell. Majority of students defined ploidy from the structure of chromosome, while it should be characterised by the set(s) of chromosome of a cell (Klug *et al*, 2016). Thus, haploid was identified as a cell having a single chromosome (no.4), while diploid as having duplicated chromosomes (no.5). A model of chromosome which related to how students understanding concept of ploidy is presented on Figure 4.8. These incorrect concepts of ploidy led to the difficulty of identifying notation for triploid cell due to the chromosomes are presented as duplicated chromosome (no.3). Also, this incorrect concept of ploidy hinders them in responding correctly to complex questions which relate ploidy with other important concepts, such as no 6 (ploidy, chromosome, and alleles) and no. 17 (ploidy-phase-alleles). The confusion with ploidy also affected them in responding to question number 7 where a large proportion of students connected the structure of duplicated chromosome with diploid (see Table 4.8).

Table 4. 8 The possible explanation of common misconceptions of meiosis from incorrect responses of MCI test for Biology Education students at Universitas Tanjungpura in the academic year of 2015/2016 following the completion of genetics module (n=66).

Meiosis CI was given after Biology education students completed their Genetics module in previous semester (academic year of 2015/2016). Students received no learning intervention with the meiosis video prior to the test. Concept on column (1) refers to the group of questions advised by Kalas et al., (2013). Column (2) refers to the number of question in the MCI test. Column (3) shows the theme of question for each number. Column (4) shows the percentage of students who gave incorrect responses per question MCI. Column (5) gives the interpretation to the possible common misconceptions derived from the largest proportion of students giving the incorrect responses who chose certain incorrect option or combination of options of MCI test.
Concept: I = Ploidy; II = Relations between chromosome and DNA, III = what counts as chromosome; IV = timings of event; V= segregation; VI = gamete formation
(*) questions which evaluate two or more concepts: no.2 (ploidy-chromosome-replication), no.6 (ploidy-chromosome-alleles), no. 13 (DNA-replication-phase), no.17 (ploidy-phase-alleles)

Concept (1)	No (2)	Topic of questions (3)	Incorrect responses (%) (4)	(5)	
I	1	the **definition** of **haploid**	80.3	81%	Haploid cells have half number as many chromosomes in diploid cells
	2*	Identifying cell represented **2n=6 before replication**	86.4	68%	In a diploid cell, what counts as chromosome is one duplicated chromosome (“X”)
	3	Choosing the **notation** of a triploid cell	92.4	84%	Duplicated chromosome (“X”) symbolises a diploid cell, the cell notation 2n=6
	4	Identifying pictorial representation of **haploid** cell	100.0	66%	A haploid cell is identified from a cell that contains unduplicated chromosome (“I”)
	5	Identifying of the representation of **diploid** cell	98.5	58% 18%	A diploid cell is identified from contains duplicated chromosome (“X”) A diploid cell is identified from contains paired of duplicated chromosome (“X”)
	6*	Identifying representation of somatic cell **2n=2, AaBbDd**	98.5	34% 17%	Somatic cell is identified from having a paired duplicated chromosome (“X”), in one chromosome: AbD-another aBd (correct representation of sister chromatids) Somatic cell is identified from having two unpaired duplicated chromosome (“X”), distribution: AaBb vs Dd (incorrect representation of sister chromatids)
II	7	Identifying what **“X” symbolises**	97.0	54% 34%	To include an idea that “X” symbolises diploid chromosome To include an idea that “X” symbolises a pair of homologous chromosome
	8	Predicting the consequence of **DNA**	97.0	57%	To include an idea that replication increases the number of chromosomes

		replication		41%	To include an idea that replication increases cell ploidy (e.g. from 2n→4n)
	9	Identifying how **DNA molecule is represented in "X"**	78.8	49% 43%	To include an idea that an "X" represents one double stranded DNA molecule To include an idea that an "X" represents two single stranded DNA molecule
	10	identifying cell(s) which share the same **number of double stranded DNA molecule**	68.2	55%	To include an idea that a duplicated chromosomes ("X") have the same number of double stranded DNA molecules as its unduplicated form ("I")
III	11	identifying cell(s) with certain **number of chromosomes**	93.9	32% 31%	One chromosome is one chromatid of a chromosome as well as one unduplicated structure One chromosome is one duplicated structure
	12	counting **number of chromosomes** of a cell	54.5	42%	One chromosome is counted as one unduplicated chromosome ("I")
IV	13*	Identifying **cell in stage(s) of meiosis** that share **the same amount of DNA** with that cell before replication	51.5	25% 18%	The amount of DNA in a cell before replication = at prophase meiosis 1, suggesting that replication happen at prophase 1 The amount of DNA in a cell before replication = at prophase meiosis 1, suggesting that replication cell segregate at metaphase 1
	14	Identifying event(s) happen at **prophase 1**	95.5	55%	To include an idea that DNA replication happens at prophase 1
V	15	Identifying to what occasion the diagram showing **a segregation between sister chromatids** contains different alleles may exist	74.2	45%	Considering this event happen at meiosis 1, suggesting the confusion between events of meiosis 1 and 2
	16	Identifying what stage of meiosis for a representation of **chromosome lining** up at equatorial cell	75.8	38% 26%	Considering the event happen at meiosis 2, suggesting the confusion between events of meiosis 1 and 2 Considering the event happen at meiosis 2/mitosis, suggesting the confusion between mitosis and meiosis
VI	17*	Identifying cell that represents **gamete from meiosis of a cell (2n=4, AaRr)**	97.0	48% 19%	Considering gamete as a 2n=4 cell contains unduplicated chromosome, suggesting the confusion gamete with daughter cell of mitosis Considering gamete as any cells contains unduplicated chromosome, suggesting gamete (haploid cell) is identified by the unduplicated chromosomes

Apart from problem with ploidy, students also showed a lack of understanding to other subordinate concepts of meiosis, such as thinking replication will increase number of chromosomes (no.8). They also have problem in understanding what counts as chromosome. Chromosome is a "*threadlike structures consisting of chromatin and carrying genetic information arranged in a linear sequence*" (King, Mulligan and Stansfield, 2013, p.83). In this sense, a chromosome will be seen as a single unduplicated structure. Prior to cell division, chromosome is duplicated, but the duplicates still joined on a point called centromere (Klug *et al*, 2016). Since the duplicates are still joined, one duplicated chromosome is still counted as one chromosome. Students have different ideas on what they considered as chromosome (no.11) (see Table 4.8). They think chromosome only have one structure either as unduplicated or as duplicated form. Students also have a problem in understanding event related to one stage of meiosis, prophase I (no.14). In this phase, two highlighted events happen, homologous pairing and crossing over (genetic recombination). Problem persists when students only recognise one of the two events, or else, thinking another event (DNA replication) happens in this phase (Kalas *et al*, 2013). Many of students of this cohort tended to have the latter idea.

4.5.2. Impact of the meiosis video: IND-1

The meiosis video was developed by anticipating common misconceptions, such as described on Table 4.6. The impact of watching video to revise students' misconceptions of meiosis was evaluated by assessing any change in students' response to the MCI test after the learning session and by assessing their thorough understanding of meiosis in the interview. Students' interview also aims to reveal their learning engagement to the video, which was validated by observation data during students' learning session. The engagement to the resource is important as it is part of supporting students' effort in actively making "*mental connection*" (Newton, 2011, p.46) to material presented on the resource. This section presents the result of resource evaluation to seventeen (17) voluntary students (which is called IND-1 group) from the general students' population mentioned in the first part (see also Appendix B-3).

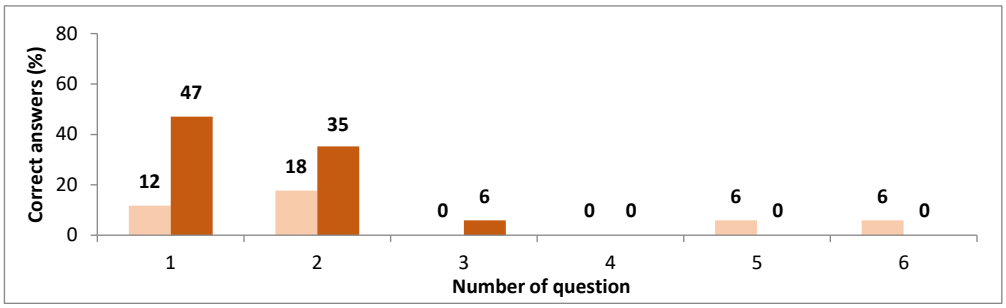
In general, there were trends of improvements to the correct responses of MCI per question after watching the meiosis video (Figure 4.9). The progress of giving correct response to MCI test question was observed in describing relations between chromosome and DNA (Group II), in counting chromosomes (Group III), and in

deciding the phase of meiosis involve in segregation (Group V). In addition, another improvement were also identified partly in responding to questions related to ploidy (Group I, number 1 and 2), and timings (Group IV, number 14).

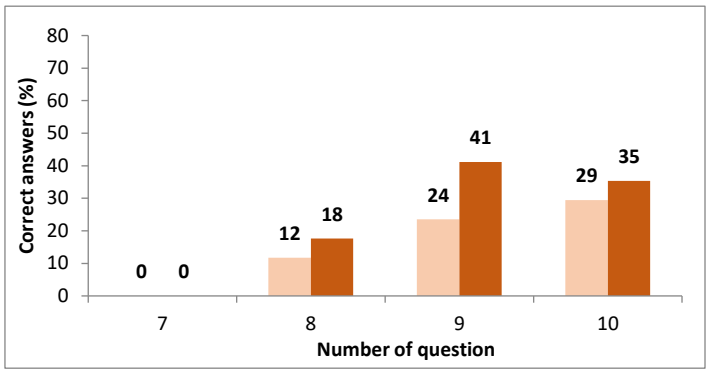
A further breakdown to the correct answers of MCI showed its proportion related to the changes from incorrect to correct answer (Figure 4.10). It is showed that the two largest changes to the correct response of MCI test was on number 15 (59% increment), and 1, 9, 12 (each of 35% increment).

Question number 15 asked IND-1 participants to identify what stages of cell division (mitosis or meiosis) shows the segregation of sister chromatids which have different alleles. The video showed the sequence of meiosis 1 and 2, including the segregation of sister chromatids. A clear visualisation of crossing over (which made the logic behind sister chromatids having different alleles) and sister chromatids segregation on meiosis 2 were linked to this change of concept. Through the interview to their perception to the resource, participants claimed the most benefit of watching the video for them were to have clearer visualisation of process in meiosis, particularly in two events, observing how the crossing over take place, and to get the clarity of the thorough events in meiosis (as showed by the result of students' perception to the video on section 4.5.3, Table 4.10). An analysis to the possible remain misconceptions to question number 15 (Table 4.9) showed that majority realised that the phenomenon asked by number 15 of MCI occurred in meiosis, however, they misunderstood the stages with meiosis 1.

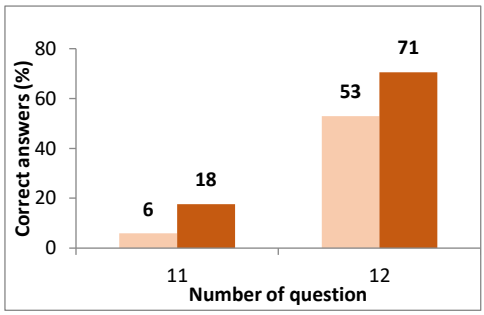
A. Group I: Ploidy, differences between chromosomes, chromatids and homologous pairs



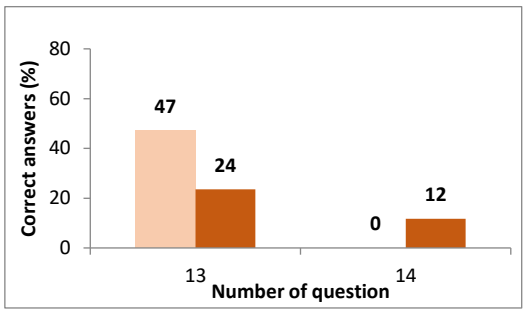
B. Group II: Relationships between chromosome, DNA, chromatids and to DNA replication



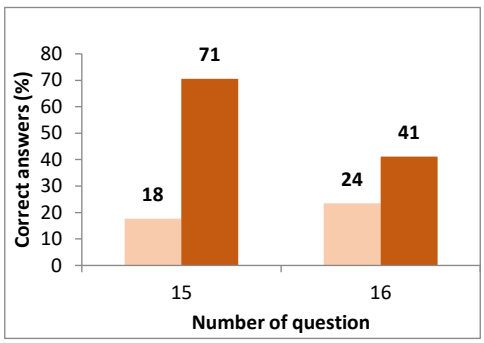
C. Group III: What counts as chromosome



D. Group IV: Timings of event



E. Group V: Segregation



F. Group VI: Gamete formation

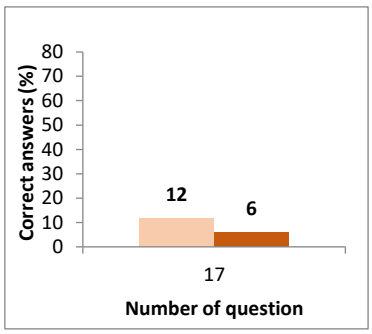
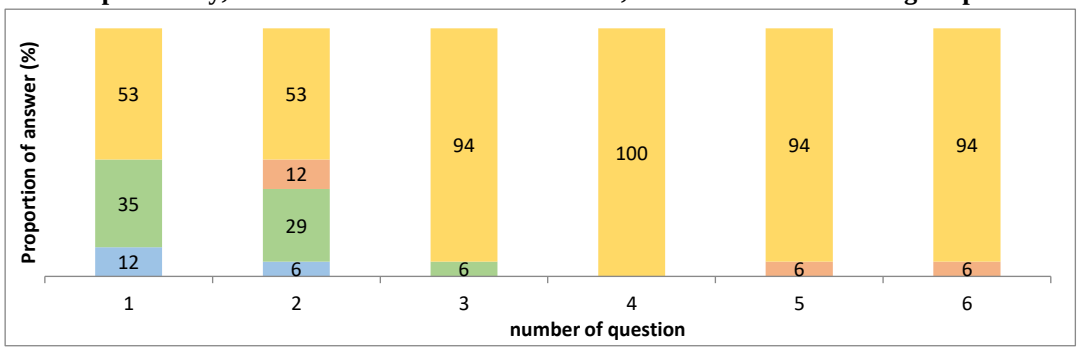
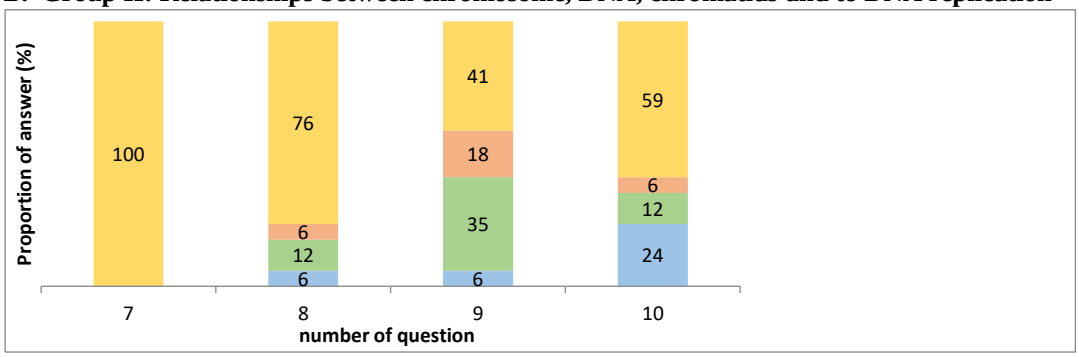


Figure 4. 9. A comparison between correct answer of MCI test before (pre) and after (post) watching the video for IND-1 (n=17). *The figure showed the comparison based on the group of question. MCI post-test was given after learning session with the video. The three biggest score improvement was observed on number 15, 1, 12 with 53, 35, and 18 point of progress, consecutively. The two biggest score decreasing was seen on number 13, and 5,6 with a gap of 23 , and 6 point, consecutively.*

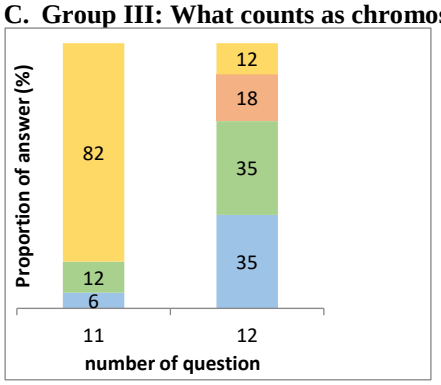
A. Group I: Ploidy, differences between chromosomes, chromatids and homologous pairs



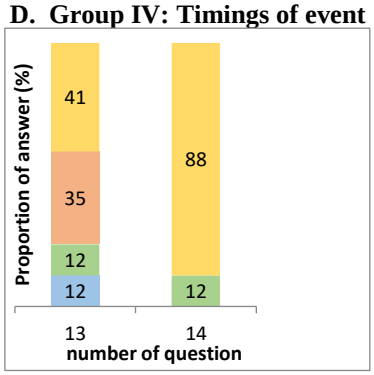
B. Group II: Relationships between chromosome, DNA, chromatids and to DNA replication



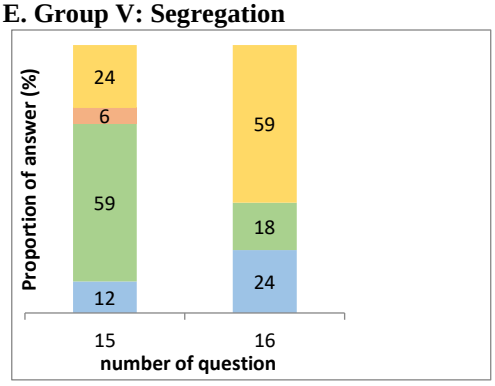
C. Group III: What counts as chromosome



D. Group IV: Timings of event



E. Group V: Segregation



F. Group VI: Gamete formation

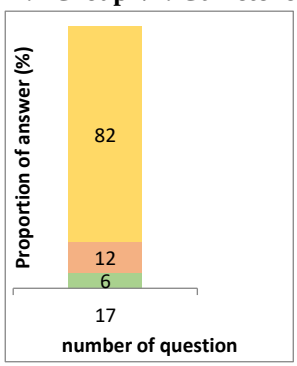


Figure 4. 10. A comparison between type of changes on the answer of MCI test before (pre) and after (post) watching the video for IND-1 (n=17). *The types of changes on the answer were presented based on the group of question. Post-test of MCI was given right after learning session with the video. (Notes: The percentage shown here was rounded up/down to the closest number automatically by Excel program, which may not result in 100% in total if each part was summed up).*

Table 4. 9 The possible explanation of common misconceptions of meiosis from incorrect responses of MCI test for IND-1 case following watching the meiosis video (n=17).

Meiosis CI was given IND-1 students completed watching the video. Concept on column (1) refers to the group of questions advised by Kalas et al., (2013). Column (2) refers to the number of question in the MCI test. Column (3) shows the theme of question for each number. Column (4) shows the percentage of students who gave incorrect responses per question MCI. Column (5) gives the interpretation to the possible common misconceptions derived from the largest proportion of students giving the incorrect responses who chose certain incorrect option or combination of options of MCI test. In a case that common misconceptions were explained as "to include the idea of …", the possible explanation was derived by calculating the percentage of students choosing one specific option. Students may include other options in their answer.
Concept: I = Ploidy; II = Relations between chromosome and DNA, III = what counts as chromosome; IV = timings of event; V= segregation; VI = gamete formation
(*) questions which evaluate two or more concepts: no.2 (ploidy-chromosome-replication), no.6 (ploidy-chromosome-alleles), no. 13 (DNA-replication-phase), no.17 (ploidy-phase-alleles)

Concept (1)	No (2)	Topic of questions (3)	Incorrect responses (%) (4)	Possible common misconceptions explained from students' responses (5)	
I	1	the **definition** of **haploid**	52.9	89%	Haploid cells have half number as many chromosomes in diploid cells
	2*	Identifying cell represented **2n=6 before replication**	64.7	64%	In a diploid cell, what counts as chromosome is a duplicated form ("X")
				36%	In a diploid cell, what counts as chromosome is a duplicated form ("X"), and replication doubles the number of chromosome
	3	Choosing the **notation** of a triploid cell	94.1	94%	Duplicated chromosome ("X") symbolises a diploid cell, the cell notation 2n=6
	4	Identifying pictorial representation of **haploid** cell	100.0	76%	A haploid cell is identified from a cell that contains unduplicated chromosome ("I")
	5	Identifying of the representation of **diploid** cell	100.0	65%	A diploid cell is identified from contains duplicated chromosome ("X")
	6*	Identifying somatic cell **2n=2, AaBbDd**	100.0	59%	To include the idea that somatic cell is identified from having a paired of duplicated chromosome ("X"), in one chromosome: AbD-another chromosome: aBd
				59%	To include the idea that somatic cell is identified from having a paired of duplicated chromosome ("X"), in one chromosome: aBd-another chromosome: AbD
II	7	Identifying what **"X" symbolises**	100.0	76%	To include an idea that "X" symbolises diploid chromosome
				29%	To include an idea that "X" symbolises pair of homologous chromosomes

	8	Predicting the consequence of **DNA replication**	82.4	50%	To include an idea that replication increases the number of chromosomes
	9	Identifying how **DNA molecule is represented in "X"**	58.8	80%	To include an idea that an "X" represents one double stranded DNA molecule
	10	identifying cell(s) which share the same **number of double stranded DNA molecule**	64.7	91%	To include an idea that a duplicated chromosomes ("X") have the same number of double stranded DNA molecules as its unduplicated form ("I")
III	11	identifying cell(s) with certain **number of chromosomes**	82.4	29% 50%	One chromosome is one chromatid of a chromosome as well as one unduplicated structure One chromosome is one duplicated structure
	12	counting **number of chromosomes** of a cell	29.4	100%	One chromosome is counted as one unduplicated chromosome ("I")
IV	13*	Identifying **cell in stage(s) of meiosis** that share **the same amount of DNA** with that cell before replication	76.5	46% 38%	The amount of DNA in a cell before replication = at prophase meiosis 1, suggesting that replication happen at prophase 1 The amount of DNA in a cell before replication = at prophase meiosis 1, suggesting that replication cell segregate at metaphase 1
	14	Identifying event(s) happen at **prophase 1**	88.2	60%	To include an idea that DNA replication happens at prophase 1
V	15	Identifying to what occasion the diagram showing **a segregation between sister chromatids** contains different alleles may exist	29.4	60%	Considering this event happen at meiosis 1, suggesting the confusion between events of meiosis 1 and 2
	16	Identifying what stage of meiosis for a representation of **chromosome lining** up at equatorial cell	58.8	70% 20%	Considering the event happen at meiosis 2, suggesting the confusion between events of meiosis 1 and 2 Considering the event happen at meiosis 2/mitosis, suggesting the confusion between mitosis and meiosis
VI	17*	Identifying cell that represents **gamete from meiosis of a cell (2n=4, AaRr)**	94.1	88%	To include an idea to consider 2n=4 cell contains unduplicated chromosome, suggesting the confusion gamete with daughter cell of mitosis

Question number 1 asked the participants to define the term haploid. The increasing score for this item was thought to be associated to the presentation of the ploidy in the video which related it to the set of chromosomes. In covering ploidy, the video showed a set of two paternal chromosomes (haploid) and two sets of chromosomes consist of two paternal chromosomes and two maternal chromosomes (diploid) (Figure 4.11). Although the introduction of thinking ploidy based on set of chromosomes through the video presentation was succeed, but it did not contribute effectively to improve students understanding on differentiating haploid and diploid based on the sets of chromosomes (as seen as lower score of MCI test for number 3, 4, and 5). The latter issue will be discussed further in the next section (see resistant misconceptions).

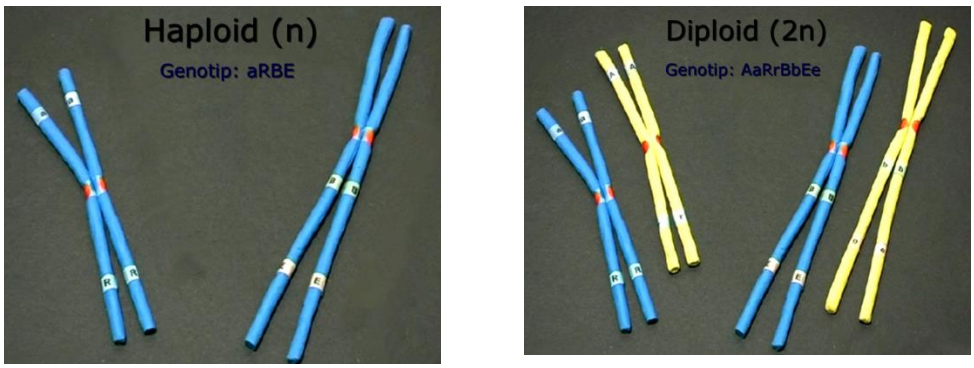


Figure 4. 11 An episode of meiosis video showing the way it explains differences between haploid and diploid cell. *This video excerpt was taken from first part of video which discuss the explanation on the terms (time 1:32). The video emphasised the differences between haploid and diploid based on the pairing of paternal (blue) and maternal (yellow) chromosomes and giving the related genotype.*

In question number 9 of MCI, students were asked to identify how DNA molecules are represented on a duplicated chromosome. The increase of the correct response of that question may link to the video which introduced the concept of one molecule of DNA for each chromosomal strand (a single unduplicated chromosome) (see Figure 4.12). The reason for why this did not succeed to improve many IND-1 students probably could link to the fact that they did not think the genetic material would duplicate when the DNA replication took place. It was thought related to the explanation on the counting number of chromosomes which highlighted that the number of chromosomes before and after duplication is the same.

> *"... The chromosome's duplicate still attaches to the original copy on an area called centromere. Because of this attachment, the two duplicates were count as*

one chromosome. Thus, we can say the number of chromosomes before and after duplication is the same." (Meiosis video narration/section I (terms)/01:07).

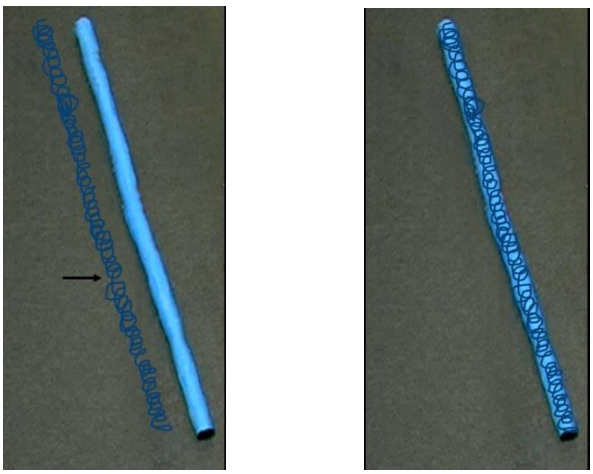


Figure 4. 12 Part of meiosis video showing how one molecule of DNA is related to one unduplicated chromosome. *This video excerpt was taken from the first part of video which discussed on related terms to meiosis (section I (terms), time 00:13). The narration for this excerpt explained that one unduplicated chromosome is made up by one molecule of DNA.*

Students incorrect idea of relating the two parts of information on the video (number of DNA molecule on a chromosome and information on number of chromosomes related following the duplication) might contributed to the incorrect answer to number 9. This was identified from the fact that 80% of students' incorrect response to number 9 were related to the idea that the duplicated chromosome ("X") is made up of one (1) double stranded DNA molecule. An excerpt from an interview with Monik (pseudonym), one of the students who gave incorrect responses to number 9, also support this thought.

I : So the duplication process will duplicate…?
Mo : The chromosomes. But it did not duplicate – what is it? Uhm… the genetic material!
…
I : But [you were saying] number of chromosomes was still the same? How does it happen?
Mo : Well, replication are making copies, copying from the first one, but the number of chromosomes are greater, but uhm.. genetic material which was copied are still the same.

(Monik/interview/21 June 2016)

She was initially relating what she informed from the video (replication did not change the number of chromosome), but then she hesitated and getting back to her old concept (replication duplicates the number of chromosome). Instead, she applied her knowledge

to the unchanged number of genetic material (molecule of DNA). In this case, she saw the intelligibility but did not convinced to have a concept change as suggested by Strike and Posner (1985).

Question number 12 asked students to count number of chromosomes of a cell that contains the duplicated chromosome (here, the duplicated chromosome is symbolised as "X"). About a half of the IND-1 students (53%) had answered this question correctly in the pre-test (see Figure 4.9). However, despite the changing to correct answer of 35% students (see Figure 4.10), there were also 18% students changed their answer into incorrect one. All the incorrect answers were related to count a chromosome as one chromatid, one of "the two daughter strands of a supplicated chromosome that are joined by a single centromere" (King *et al*., 2013, p. 81 (see Table 4.9). This showed that some students still confused to the idea of what counts as chromosome, which was evidenced by the inconsistency in counting the number of chromosomes in response to question number 11 and their answer during the interview. Lala and Nana (pseudonym) was one of students who had a change into correct answer for question number 12. However, she counted number of chromosomes as number of chromatids for number 11. When she was interviewed, she did not certain with her answer, and eventually changed her answer from initially counted chromosome as "X" into counted chromosome as chromatid. On the other hand, Kelly (pseudonym) was one of students who changed her answer for question number 12 into incorrect one. She also was changing her answer from counting chromosome as "X" and eventually as chromatid when she was asked the same question as Lala and Nana in the interview. Thus, despite the increase on correct answer for number 12, it could not be said that students getting an improved understanding to what counts as chromosome. When analysed, this might be caused by a limited presentation of the related concept. The only section of the video that may help students to understand the two forms of chromosome was the section explaining that chromosome number before and after replication is the same (section I (terms) time 01:07, see discussion for number 9).

4.5.3. Resistant misconceptions of meiosis: IND-1

Despite some improvements on students' understanding of meiosis which was related to the content of the video, there were questions with very low correct answers (or in some cases, no correct answers). These areas reflected the misconceptions that had not yet

been overcome successfully by watching the video. An analysis of each component was done to give insight into the revision to the video content and presentation.

1) The idea of "diploid and haploid chromosome"

In spite of the fact that some participants changed their idea of the definition of haploid into "one set of chromosomes" (number 1), the changes were not followed by having the correct representation of what considered as set of chromosomes (number 3, 4 and 5). Students still retain the concept of diploid cell was symbolised by duplicated chromosome, which was shown on their incorrect options for number 2 and 6.

During the interview, students' incorrect idea of ploidy was reflected as "haploid chromosome", which was repeatedly mentioned in the interview. Two excerpts below exemplify that idea of "haploid chromosome" in the interview talk (bold formatting used for emphasising):

> "[I am not sure] *how* ***haploid and diploid chromosomes*** *are. How do the homologs look like. I continuously remember them differently, and just forget"* (Clarisya/Interview/22 June 2016)

> *Interviewer (In): So, how do you differentiate haploid from diploid?*
> *Indah : This* [pointing at a picture of chromatid]. *Consider this as one "n"* [refers to haploid in the conversation]. *One chromatid.*
> *In : Ah, so, one chromatid is a haploid one?*
> *Indah : Yeah, but… then why they have this term of* ***haploid chromosome and diploid chromosome****? Well, I got confuse*
> (Indah/Interview/21 June 2016).

Moreover, students were likely to define ploidy based on its literal meaning without connecting to the context of term (di=two, haplo=half). Thus, many of them fell into the trap of translating diploid as a structure that is composed of two unduplicated chromosomes or chromatids ("I") led them thinking diploid as the duplicated structure of chromosome. An excerpt of Indah (above) and Dodo (below) may explain further this phenomenon.

> *Interviewer (In): So, what ploidy of this cell do you think?*
> *Dodo : Diploid*
> *In : What is the reason?*
> *Dodo : Because haploid means only one, and diploid is two. Because it* [diploid] *is 2n.*
> *In : What do you mean by two?*
> *Dodo : I mean they have been combined. Attach into a chromosome.*
> *In : Do you mean that if they are attached to each other, then they are called diploid? And if they are on their own they are called haploid?*
> *Dodo : Yes.*
> (Dodo/Interview/21 June 2016)

This idea could be reinforced by the presentation of haploid and diploid cell on the textbooks. Students typically learnt the concept of haploid/diploid when they learn about cell division. Many textbooks (e.g. (Reece *et al*, 2014; Klug *et al*, 2016; Raven and Johnson, 2002) introduce this idea immediately before they discuss mitosis and meiosis. The presentation of somatic diploid cell with duplicated chromosome in the beginning of meiosis and the presentation of gamete haploid cell with unduplicated chromosome at the end of meiosis may be one of the reasons for this pervasive idea.

Although the video tried to present on the explanation of the concepts by highlighting the differences between haploid and diploid cells (Figure 4.11), it may not have succeeded in overcoming problem with ploidy. It is possible that students may miss this explanation because it was given in the beginning of the video.

2) Erroneous idea regards to structure of chromosome: what counts as chromosome and what "x" is represented

Confusing the concept of ploidy with the structure of chromosome, as demonstrated above, is a common problem in understanding meiosis (Chinnici and Torres, 2004; Wright and Newman, 2011). Furthermore, (Clark and Mathis, 2000) identified that the problem was related to the difficulties in differentiating structure of chromosome, chromatids and homologous pairs. A difficulty in understanding ploidy may be due to the difficulty of understanding the structures of chromosomes. Below are some incorrect ideas of concepts regards to chromosome structure which contribute to the low correct response of MCI on number 7 and 11 on Figure 4.10.

From analysing question number 11 (Table 4.9), it is clear that most participants (82.4%) held two ideas of a structure that refers to what counts as a chromosome, a duplicated chromosome ("X"), or an unduplicated chromosome (a chromatid) ("I"). A point of confusion (inconsistency) in counting number of chromosomes was shown, for example by counting chromosome only as "X" in number 11, while counting it as "I" in number 12, or the other round (see discussion for number 12 on previous section). In this case, watching the video had not yet supported an effective counteract idea to tackle this problem.

In responding to question number 7, majority IND-1 students (76%, see Table 4.9) relating the duplicated structure ("X") to concept of diploid, which brought to the prominent problem with ploidy. Another contributing factor was the idea of seeing "X" as a pair of homologous chromosomes (29%). The confusion of thinking "X" both as

sister chromatids and the homologous chromosomes was identified clearly in the interview. Except for Jojo who thought sister chromatids referred to chromatin, most students could identify sister chromatids referred to the two chromatids on a chromosome ("X"). Interestingly, in identifying homologous chromosomes, students held a working definition of "*having the same length of chromosomes' arms and the same length of centromere*". By using the definition, they initially were able to identify homologous pair as a pair of paternal and maternal chromosome. However, due to the same definition could be applied to structure of sister chromatids (Figure 4.13), many students eventually consider sister chromatids and homologous pair shared similar structure, the "X". The differences between those two structures had been presented on the video, which emphasise that homologous chromosomes are a pair of paternal and maternal chromosomes that contains the same genes. However, none of students use the content of the video as their reference in answering the question, suggesting that the content made a small impression on the conceptual understanding of students.

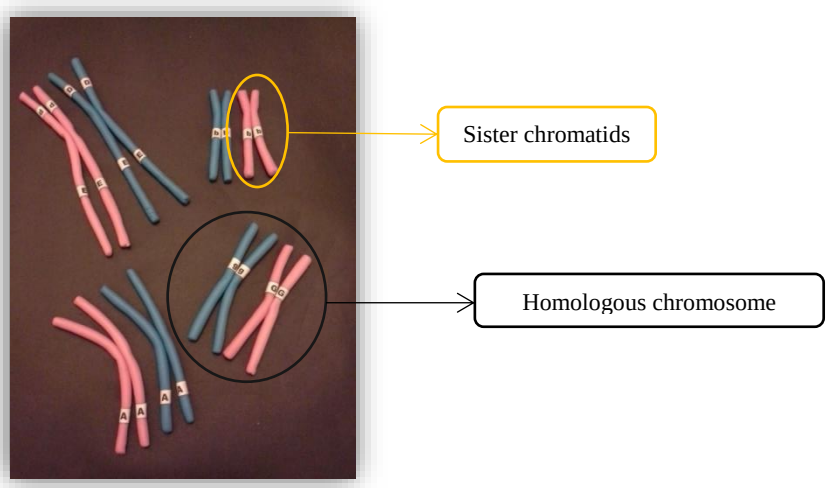


Figure 4. 13 The differences between sister chromatids and homologous pairs which was expected to be spotted by IND-1 participants. *Students held the working definition of homologous chromosomes of having the same length of chromosomes' arms and same length of centromere which could be applied for both sister chromatids and homologous chromosomes. Picture was taken from one of elicitation technique in the interview.*

Mistaken idea of what considered as gametes

The impact of having an incorrect understanding to the haploid cell may lead to difficulty in predicting the gamete produced at the end of meiosis. Students typically classify one cell as a gamete cell based on the fact that it is a haploid. The

misunderstanding of 'haploid' means having an unduplicated structure of chromosome, they tend to find a gamete cell with that specific structure in mind. This caused the majority (88% out of 94.1% students who gave incorrect answers, see Table 4.9 question number 17) include a daughter cell of mitosis (also has unduplicated form of chromosome) as a gamete cell.

Further to the confusion between gamete cells (meiosis product) and daughter cells (mitosis product), students' incorrect understanding of the term "gamete" led them to anomalous ideas when identifying gametes. Students started with correct statements about gametes, such as "*a gamete receive a half of its genetic material from its father and another half from its mother*", *a gamete is a haploid cell, and a gamete (haploid cell) has a half number of chromosome of its parent cell*", however, they misunderstood the expanded idea leaving them with error in identifying gametes which, to the researcher's knowledge, have not yet been discussed in the literature. An interview excerpt is included below to give an example of the types of incorrect ideas students have about gamete. To give context on how students think about gametes, several models of "chromosomes inside a cell" (Figure 4.14) were shown to students in the interview. They used the model they chose to explain what they think of possible gametes.

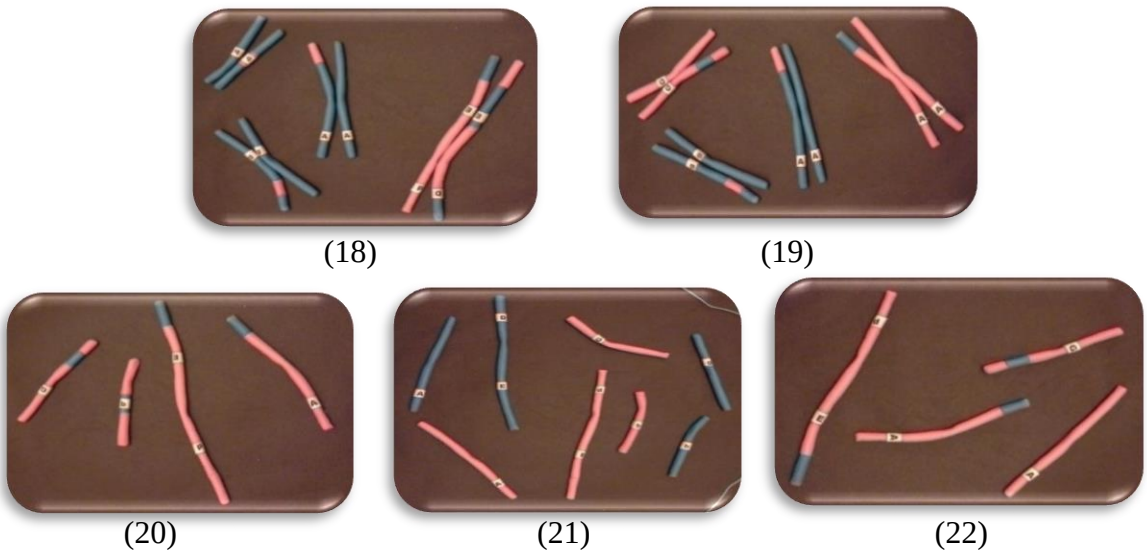


Figure 4. 14 Images of model of chromosomes in a cell showed to IND-1 participants to identify possible gametes produced by meiosis of a parent cell.
Pictures were shown as part of series of picture containing cards used to probe students' understanding of meiosis during interview. Possible gametes were identified based on the chromosome structure and the genotype of a cell. Genotype of each cell is (18) AabbggDdEE, (19) AAAAGGgg, (20) AbGdE, (21) AabbGgDdEE, (22) AAGdE (consecutively). Students were expected to choose (20). The expected answer for a representation of gamete is no. 20.

As students observed the possible pictures of gametes (Figure 4.14), they were provided with a picture of parent cell to enable them visualising process of meiosis in determining the gamete(s). Below are interview excerpts which showed students' erroneous ideas of gametes:

1) Gamete (haploid) cell has half number of chromosomes of parent cell (diploid), and what considered as chromosomes in both cells are "X"

This idea was represented by Dodo: chromosome should always be counted in duplicated chromosome ("X"). Gametes are identified from counting the number of chromosomes to be half of those of parents. If gametes exist as a single (unduplicated) chromosome such as depicted on number 20-22, the two single chromosomes will join to form the duplicated chromosome ("X"). It suggested an idea that for him, the duplicated chromosomes may not come from the chromatid duplication (DNA replication), but from the joining of two chromatids.

Interviewer (In) : ... which cells from number 18-22 that possible as gamete produce from meiosis of parent cell?
Dodo : number 18.
In : For what reason?
Dodo : (pause) well, it looks like that it has been ... join together ... ehm…number 18 and 19.
In : And both because there is a join between the chromosomes?
Dodo : Yes.
In : So, number 20-22 are not possible as gametes?
Dodo : I don't think so. Because ... well, it looks like this one [number 21] *and that one* [number 22] *are possible, uhm… if they* [the chromosomes] *are joint… If they are combined, the number* [of chromosome] *will it be half of the parents', which is eight? If they* [chromosomes] *are joining together, the number of chromosome will be 4* [number 21]. *But, is it okay if the lengths of chromosomes are not the same? If* [chromosomes are joining in] *this* [number 20] *it will produce 2 chromosomes. And that one* [number 22] *too. So, it will not the same with the parents.*
...
In : So, you were saying that number 21 and 22 were not possible, and that because…?
Dodo : if they [chromosomes] *are to join in, they will produce only two, not four chromosomes,* ***not half of the parents****.*

(Dodo/Interview2/21 June 2016)

2) Gametes must have the same alleles as parents

The resemblance of the gamete cell to its parent cell was translated by Indah as the gamete having the same alleles as its parents. In this case, she did not consider that in fact a gamete cell received only half of chromosomes as those of parent cell (reflected as one of each allele of paternal and maternal chromosomes). This is to ensure

fertilisation ("a fusion of two gamete cells" (Klug *et al*, 2016)) result in diploid cell that has the same number of chromosomes/alleles as its parents.

Interviewer (In): … which cells from number 18-22 that possible as gamete produce from meiosis of parent cell?
Indah : Hmm… I still confuse. I forget. Uhm… 4 [homologous pairs on parents] so, … four (4) Big G little g Big A, big D, little b.. with this (number 21) … b is missing. Well, there must be an "adoption" maybe? 1, 2, 3, 4… 4, 5, 6, 7. There are 7 alleles. So, --- 7 alleles [she is looking at number 21] *1, 2, 3, 4, … 5, 6… --- --- maybe this one.*
I : Number 21?
Indah : It is likely so.
I : And that's because…?
Indah : Because there are 7 alleles here. They should have all alleles. If one of them is missing, well…they [the missing alleles] *just being suppressed… let us consider … maybe there is an exchange, but, .. we narrow it down to them (missing alleles) being gone. It must be the daughter cell. Two… half of the trait of parents. Half of father trait, half of mother trait. So, I count it from the seven alleles producing seven traits.*
I : Does it mean, a gamete has to have all alleles of its parent?
Indah : Yes. ***Half from father, and half from mother****…*

(Indah/Interview2/21 June 2016)

3) Gametes (haploid cells) refer to intermediate and final product of meiosis.

Students misconceived gametes as any haploid cells in meiosis, comprising the end product of meiosis 1 (haploid cells with duplicated chromosome), and the end product of meiosis 2 (haploid cells with unduplicated chromosome). Qomar, Jojo, Rani, and Fiska, all thought that haploid cells involved in the process of meiosis are called gametes. This misconception of gametes led students to include the daughter cells of meiosis 1 (which are haploid) as gametes.

Interviewer (In) : Which ones are gametes?
Qomar : --- 18 … and also 19. --- 20… wait (he laugh) --- 18 and 19
In : alright. Now, what is your reason for choosing number 18 and 19 as the possible gametes?
Qomar : Em.. all genes on here [parent cell] *are found in here, …. In these two pictures.*
In : What about number 20? What makes you hesitate to call it gamete?
Qomar : Because only… only gene b that is not find here
In : So, how should it be?
Qomar : --- all --- (whispering) --- --- --- (looking at picture of parent cell)
In : Well, what if we look at number 21? What do you think? Is it possible as a gamete?
Qomar : Yes, it is.
In : what about number 22?
Qomar : --- --- (looking at the picture) --- --- em,.. no.
In : For what reason?
Qomar : Because there are no… that gene.

In : What gene that is not there?
Qomar : --- --- well, I think it could be the one. Yes, I am sure. Yes.
In : So, only number 20 is not possible as gamete?
Qomar : --- --- --- Yes.
In : So, why does number 20 become the only cell that is not possible as gamete of the parent cell?
*Qomar : --- **Well, all of them are n*** **[haploid],** *I guess. --- --- so, I think it could also be a gamete.*
In : So, do you mean all of them are possible as gamete of the parent cell?
Qomar : Yes, every of them are possible gametes of this parent cell
(Qomar/interview/22 June 2016)

4) Gametes must have a similarity to the parent cell, at least have one exact chromatid/chromosome that of parent

Nana failed to correctly identify what counts as a gamete. She stated that a gamete must be similar to its parent cell. She incorrectly expanded this idea by stating 'a gamete must have similar chromosome as on its parent cell'. She mixed up the term 'gamete' with 'gene' (e.g. she stated gamete 'b' while it should refer to gene 'b'), during her interview. This misconception made her think that a gamete should have two alleles (e.g. AA). In her description, number 20 (see Figure 4.14) was the only model of cell that did not meet her criteria of gamete because none of chromosomes has two copies of alleles, because they are not either in duplicated form, diploid, or having a non-disjunction).

Interviewer (In): … Is it possible for number 18 becomes one of gametes produced by meiosis of a parent cell?
Nana : Yes, it is possible
In : Why do you think so?
Nana : Here, there is gamete which looks like … the first gene, [on parent cell] *before meiosis. There is gamete b* [gene b], *and after meiosis, there is also gamete b.*
In : We talk about parent cell here, right?
Nana : Yes, the parent cell. And there is paternal, here we have paternal too. Well, there is a thing that I did not understand yet. What the pink part is for? I don't get it. Well, here there are2 gametes that looks like the parents. On number 18, and 19 as well.
In : Does it make it [number 19] *as a possible gamete?*
Nana : Yes, it is possible. No 20? Oh, no. Because there are no gametes [chromosomes] *that look like the parents'.*
In : OK. So, that is because there is not any similarity with the parent cell?
Nana : Yes.
In : What about number 21 and 22?
Nana : number 21? Yes, it is. Only one chromosome that looks like the parent cell. And that's only looks like one parent cell. Oh, no, two parents [paternal/maternal chromosomes]
In : What does it mean to have two chromosomes that look like the parent cell?

Nana : Well, so it could be categorised as gamete
In : What about number 22?
Nana : Em… nothing [similar]. *Erm.. well, there is! So, it could be a gamete. Because there is a similarity to the parent cell!*

(Nana/interview2/21 June 2016)

From analysing various students' incorrect concepts of gamete, the main problem of understanding it could be related to its genotype. A gamete cell was defined as only having one copy of allele of its parent cell. Kindfield (1994) described problems in understanding meiosis related to the correct visualisation of the distribution of alleles during stages of meiosis which related to the production of gamete. In characterising a gamete cell, students adopted practical strategies regard to the definition of a gamete, but they incorrectly perceived the genotype. For example, Tari, the only student responding correctly to question number 17 in the post-test, recognised a gamete cell from having unduplicated chromosomes, and from having half the number of chromosomes that the parent cell has. Her understanding showed as a correct answer to no 17 of the MCI test. However, in the interview, she did not pay attention to the genotype of a gamete, which made her include number 22 (Figure 4.14) as one of possible gamete cells although the cell contains two alleles A (AA) which is not possible to obtain through a normal meiosis. Thus, to have a comprehensive understanding of what counts as gamete cell, students have to understand the events of meiosis (including the distribution of allele) in producing gametes.

4.5.4. IND-1 Students' perception of the video

In addition to assessing the advantages of the video in reducing students' misconceptions through concept attainment testing using MCI and interview, students' feedback on the video was also collected. The evaluation of instructional materials and activities was performed to inform the revision of the resource (Gagné *et al.*, 2005). This evaluation was focused on the clarity of the content presented in the video, and whether the content was interesting. Students' interest acts as initial point in making "mental engagement" (Newton, 2011, p.46). The latter is important to build an understanding of a topic by linking students' existing understanding with new knowledge extracted from the video.

Students' engagement with the video was assessed through observation (by analysing video recordings of students' behaviour as they watch the video, by analysing

observation notes), and through the interview. In general, students pay attention to the video since the beginning of the play. However, attention was not fully given to the video, since some of them were doing unrelated task while they watched the initial part of the video (Observation notes, 9 June 2016). Students gave more attention to the video at the point it showed the first stage of meiosis. The reason for this may be linked to the fact that many students were attracted to the analogy of "spindle fibres" which protracted and retracted from centrosome to the centromere of chromosome (for students' detail comment see Table 5.10). Another reason for not giving full attention to the beginning part of the video was the assumption that the meiosis video provided the same information as other videos of meiosis, which was explained by Qomar. However, he changed his mind later on when he realised that this video also showed the change of composition of alleles (genotype) which he did not find on watching other videos of meiosis. The reduced attention to the initial (introduction) part of the meiosis video where an explanation of subordinate concepts of meiosis (e.g. structure of chromosomes and ploidy) were given may be related to low percentage of having correct idea of fundamental concepts in understanding meiosis.

From researcher observations, the most interesting part of the video was possibly the second part, indicated by many students looking surprised and reacting by saying "ah-ha". This part of the video presented how more than 8 million variants of gametes in human (46 chromosomes) were possible to form from different random distribution of paternal and maternal (without including the possibilities from genetic recombination or crossing over) (Observation notes, 9 June 2016). Since students leave with big impression of this part, it was expected that students would explain what they understand from watching this part in their interview. However, this was not the case. From all participants, only Lala mentioned this part in her interview. She could not understand the way random distribution of chromosomes contributed to genetic diversity. Bold formatting in the interview excerpt below used for emphasis.

In : Oh, do you mean the second part of the video? Is it a part where the video shows random distribution of chromosomes?

La : Yes, that part. I do not really understand. Uhm… ***like the combination of four, and then combination of 3. I do not understand. Why it becomes like that. Why… for example, they were all females, and they were all males****. I do not know.*

In : Do you mean that you do not know how chromosomes were distributed into a group that all of maternal chromosomes, and how they were distributed to make another combination?

La : Yes, the combination. For example, there were two combinations, three combinations, and four combinations. Just like how it was presented on the video.

(Lala/Interview2/22 June 2016)

She recognised that one cell may undergo several possibilities with regards to the different random distribution of paternal and maternal chromosomes. She was able to explain that there were different combinations of paternal and maternal chromosomes, however, she could not understand why there were four possibilities of chromosome segregation at metaphase meiosis 1 which lead to the production of eight variants of gametes. The confusion might be due to video introduced the process of allele distribution (on the chromosomes) at the same time it introduced the term paternal and maternal chromosome. The reason for this confusion was claimed by her classmate, Rani (see Table 5.10). In her interview, she mixed up the term 'maternal and paternal' chromosome with gender (females and males). When students were expected to process two new concepts at the same time (concept paternal and maternal chromosomes and segregation/combination process in random distribution of chromosomes), it may reduce students' capability to understand those concepts due to the limitation capacity of working memory (Cook, 2006). Therefore, though this part was observed as the most interesting part of the video for students, it did not contribute to students' understanding of the concept of meiosis.

Based on interview, students pointed out that the weakness of the video was due to the speed the content was delivered. One of students, Nana, was observed to make notes on terminology (introduction part of the video), however, she stopped this activity when the video moved on to the first part of meiosis (Observation notes/19 June 2016). In the interview, she explained her reason for stopping taking notes as the speedy transition between terminology which she could not follow. The fast content delivery of the video also perceived by four other students (see Table 4.10), which was coincided with the two (out of 10 students) on the pilot study (see Table 4.7). This phenomenon may also indicate that students may overflowed with the latest information/understanding of the meiosis concept. Schnotz and Grzondzeil (1996) showed that video did not always succeed on teaching concept understanding because of the brief display of moving object. In this case, Narayanan and Hegarty (2002) suggested to giving extra time for students to extract information from the video. Since

an additional time for each slide may increase the total length of the video, it is more effective to design a task which allowed students to extract information while they were reflecting on what they have seen on the video.

Alternatively, a repetitive play of the video is was considered as a solution to overcome students viewing rapid delivery of information on the video. Sanger et al., 2001 (in Cook, 2006) suggested showing the same animation more than once or giving control to the students to stop at key points of the animation to view static images. However, Chandler (2004) showed that giving students a complete control may not entirely effective, particularly if students did not have meta-cognitive ability which enable them to reflect to what part they need to revise the information for their understanding (Lowe, 2004). Thus, it is more beneficial to leave the pause functionality to the instructor based on students' demand in the class. This choice will ensure students to re-watch the part they did not clear. It also enables instructor/researcher to understand to which point students are struggling to understand. The latter data will be used to improve the video.

Table 4. 10 A resume of IND-1 students' perception to the meiosis video (n=17). *A theme of students' perception is presented on column (1). Students' views were coding from the interview (column 2). An example from the interview excerpt is presented on column (3)*

Classification	Description	Example of students' excerpt of interview
Advantage of the video	Showing the process of meiosis on each stage [7]	*"… For example, if we compare to what I got in the class [genetics module]. Lecturer used only still picture when she explained the process, no model [of chromosome], and simulation to how chromosomes are aligned on the equator, and how they move to the pole. … This is different when I watched the video. The process is showed from the beginning, starting from the pairing. And uhm… making this uhm and then go to the equator. [Video showed] phase by phase."* **(Ulan/interview/meiosis)**
	Showing the connection between spindle fibres and random assortment [4]	*"… typically centriole [here she meant spindle fibre, red] was not focus of attention, only presented as lines. So, I thought it was just an imaginary, not real. On the video, [we can see] spindle fibres which attach to centriole uhm… centrosome.it is clearer on the video, [the reason for] how the division happen."* **(Lala/interview/meiosis)**
	Getting new information/new way to understand meiosis: - related to ploidy[1] - terms of paternal and maternal chromosomes [2] - random attachment of spindle fibres of one pole to one of chromosome (meiosis 1) , or to one of chromatid (meiosis 2) [4]	*"… both duplicated chromosomes and unduplicated chromosomes could be categorised as haploid"* **(Monik/interview/meiosis)** *"…From the video I knew about paternal and maternal chromosomes, which I did not know before… Well, I have an image of [offspring got] half of chromosomes from its parents. Watching the video make that picture clearer, having [chromosomes from] father and mother"* **(Rani/interview/ meiosis)** *"Then I knew about spindle fibres… I did not get that the spincle fibres make an independent attachment… I thought it was by design, but it was not."* **(Sisi/interview/meiosis)**
	Different presentation to the typical learning media of meiosis [3]	*"the video helped me (in learning meiosis) … the pictures in the text book just show what prophase looks like without any further explanation. Well, it is actually, on the text, but it is in another part. But in the video, it shows me directly, say, where the chromosomes attach, how recombination occurs, for example this part (blue) has a part of that (yellow) … it has been crossed over".* **(Jojo/interview/meiosis)** *In typical videos [of meiosis] … they only present the chromosomes, not the genes [genotype]. [for example] the letter A. Because I think that [the inclusion of genotype] made us know how they [gametes] are varied. I did not find it on other videos. [They just] represent the chromosomes.* (Q**omar/interview/meiosis)**
Limitation of the video	Fast narration [4]/ Fast narration and animation display [1]	"*But I guess .. well.. the narration was so fast (laughing). I thought I would like to understand this, say prophase, it [the video] has been continued to another phase. Oh,*

		my God, I thought, I have not… so, I used to see the video, and then listen to narration while understanding the phases. I even re-drawn [meiosis phase]. But when I saw the video [resource], I could do nothing, It just moved to the next section… though I still want to watch that part [prophase]" **(Ulan/interview/meiosis)**
Suggestion to revise the video	Repeating the play (more than once) [1]	*"…Because I am a visual learner, so I have to get an image [pictorial representation] while being explained. The video … well, it was not fast actually, but watching in one go, it is too passive. It is not because of the fast narration, I guess, but… the narration [content]. I just cannot do [understand] from one time watching, I have to repeat that. The explanation was not too fast, but it need to be repeated"* **(Tari/interview/meiosis)**
	Individual access to video [1]	*"I thought it supposed to be given to individual student. Because if we only watch that on campus, uhm in a class, maybe there are someone who cannot concentrated. If it is me, I can review it [the material] while at home until I understand"* **(Clarisya/interview/meiosis)**
	Give a highlight/interactive questions [2]	*"Maybe it is [the suggestion] related to the speed of narration. I think it is too fast. I have not understood it [a part of video] yet, it has been changing. When in it is in a [formal] lecture, then it could be stop at some points to have a question-answer session with students. … The explanation [on the video] could be paused while giving an interactive question. If I just asked to watch, my mind used to wandering (laughing)"* **(Indah/interview/meiosis)**
	Reduce the speed of narration/display [5]	*"My first advice would be to slower the speed of narration… slowly. At some points, there are parts without narration… other parts all good. Narration matched to the presented slide".* **(Dodo/interview/meiosis)**

4.6. Reflection on the first cycle of the development of the meiosis video

The initial idea of developing a video resource illustrating meiosis was to show meiosis as the continuous process that contributes to the genetic diversity, while at the same time providing students with information to challenge their misconceptions to subordinate concepts of meiosis (see section 4.5). Of all subordinate concepts, the video did not fully facilitate better understanding of ploidy and structure of chromosomes, these the two concepts are the most difficult misconceptions of meiosis to change (Kindfield, 1991; Wright and Newman, 2011; Chinnici, 2006). Misunderstanding of ploidy and chromosome perpetuated students' confusion in determining gamete cell leading to erroneous ideas of visualising gamete.

A review of the content of video to assess why the introduction of change in subordinate concepts is less effective was originally thought to relate to the concepts' delivery on the video. However, this actually related to the high-density information lead to high intrinsic cognitive load of the video requiring students to use their capacity to think while extracting information from the video. As suggested by Sweller and Chandler (1994) and Cook (2006), high intrinsic cognitive load leads to the use of more working memory capacity and results in students being less effective in focusing on extracting correct information from the educational resource. Presenting students with all information about meiosis they need to learn at once did not provide them with much of an advantage in revising their concept of meiosis. In conclusion it may be better show the video in smaller sections which will help students to focus on their revision of important concept in meiosis once at a time.

The length of the video may have limited students' focus on its introduction part, where subordinate concepts were explained. Although students seemed to have been captivated by the information regarding the generation of genetic diversity (parts 2 and 3 of the video), they did not seem to process the information effectively. This was evidenced by the noticeable changes that were identified in this project where students acknowledged that meiosis is a continuous process, (e.g. their higher scores in the MCI for identifying individual stages of meiosis such as metaphase 1). However, the revision of the subordinate concepts of meiosis, particularly those related to concept of ploidy and structure of chromosome was not successfully achieved (as shown in section 4.5.2). The problem was thought to be related to the reduced attention paid to the part where these concepts are explained identified from interview and based on observation (as discussed in section 4.5.4), This situation gave them less chance to revise the

subordinate concepts which were explained in detail during the initial (introduction part) of the video.

Thus, to promote better understanding of the subordinate concepts of meiosis, it was thought to be important to focusing students' attention to the beginning part of the video. Rieber (1990) emphasised that cuing students' attention to the significant parts of the video will allow them to better extract the intended information. This suggestion aligns with the presentation of smaller sections of the video as discussed in previous paragraph. Thus, the focusing attention on the introductory part could be achieved by giving students enough time to understand the concepts before continuing to the next section (the part that discusses the process of meiosis).

Another strategy to focus students on the introduction of the video was to design the additional tasks related to the content of the video which will encourage them focus on watching the video from the beginning. This step corresponds with creating a more active learning strategy to enhance the benefits of watching an educational video, as suggested by Brame (2017). The follow-up activity was thought to designed as a task of simulating meiosis, which requires students to apply their understanding of subordinate concepts, such as differentiating sister chromatids from homologous chromosomes, and the concept of ploidy. In addition, by asking students to carry out simulation activity, it is expected that students would also correct their erroneous conceptualisation of gametes, due to the fact that they have to perform chromosome segregation which demand the understanding of random assortment of chromosomes.

4.7. Improvement on the meiosis video

4.7.1. The design and development of additional task

The additional activity was originally planned to be a simulation of the concept of meiosis as shown in the video using the same the chromosome. Subsequently it was decided to use a different model of a chromosome to prevent students imitating the process of meiosis shown in the video, without consciously trying to understand the concept. Newton (2011) suggested creating an activity which stimulates students to think about what they have learned and apply it in a new context to ensure concept understanding. Moreover, the use of clay/plasticine chromosome model had practical limitation and thus this model of chromosome is not recommended due to it cannot be used more than once. Thus, another simple model of a chromosome was selected to replace the clay/plasticine model of chromosome.

Ideally, the new chromosome model should look very similar to the model of the chromosome used in the video (i.e. have a rod-like structure and being able to use in the visualisation of crossing over,). Several recommended models of chromosome were identified (see section 4.3), however, none met the two required attributes mentioned above. Using chromosome models made of laminated paper did meet these criteria. This new model also allowed for additional attachments to symbolise gene loci/alleles to support the concept of crossing over (see Figure 4.15).

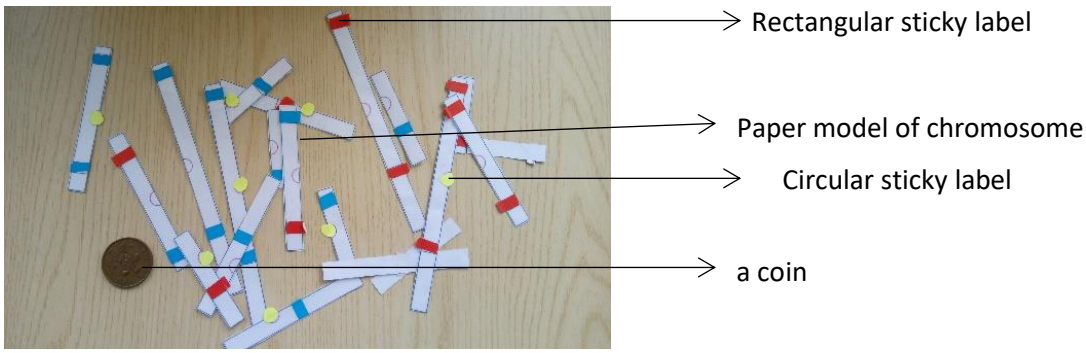


Figure 4. 15 Materials used in the additional activity following the meiosis video. *The materials consist of paper model of chromosome, red and blue rectangular (symbolising gene loci) and yellow circular (symbolising centromeres) sticky labels. A coin, added to the picture for the purpose of scale, is used during the activity to achieve random decision making.*

The additional activity was designed to simulate meiosis using paper chromosome models. This activity emphasised the randomness of crossing over and independent assortment of chromosomes as contributing factors to genetic diversity (Klug *et al*, 2016). Suter-Giorgini (2010) showed that the visualisation of random factors could be demonstrated by flipping a coin (as shown in the Meiosis Card activity she designed). A simple guide for this meiosis simulation was designed. Students were tasked with building correctly labelled paternal and maternal chromosome models and subsequently simulating each stage of meiosis, based on what they had learnt from the video. The task was made available in Indonesian and English (Appendix B-4, B-5)

4.7.2. Integrating the simulation activity with the meiosis video

The follow-up activity was designed to increase students' engagement with the content of meiosis video. The students were informed of this activity beforehand with an expectation to increase engagement to the video. Based on the reflection of the first cycle, it is decided to show the video in three separate parts to improve students' understanding on meiosis.

4.8. Evaluation of the impact of the meiosis video and follow-up activity on students' understanding: IND-2

The difference between the first and second evaluations of the meiosis video was the post-video activity after watching the video. In addition to the observation of how students watch the video of meiosis, observation of how students simulated meiosis using the activity was made. Due to availability of only one observer (researcher), a video or audio recorder was located with each group of students to record students' reaction during the simulation and analysed later.

The second evaluation involved the second group of Indonesian students (IND-2) and the counterpart case of UK students. The latter (UK case) will be presented in section 4.9.

4.8.1. The existing understanding of meiosis among Biology education students of IND-2 cohort

Students' (IND-2) understanding of meiosis was measured by analysing their responses to the MCI test and interviews. As in the first case, the understanding of meiosis of year 3 Biology education students at Universitas Tanjungpura (2016/2017; n=78) was investigated to get a base level understanding of this cohort (Figure 4.16). Students' incorrect responses were further analysed. The largest percentage of students choosing an option (for multiple choice type) or certain combination of options (for multiple true/ false). Analysis of responses was used to identify common misconceptions held by this cohort. A summary of findings is presented in Table 4.11.

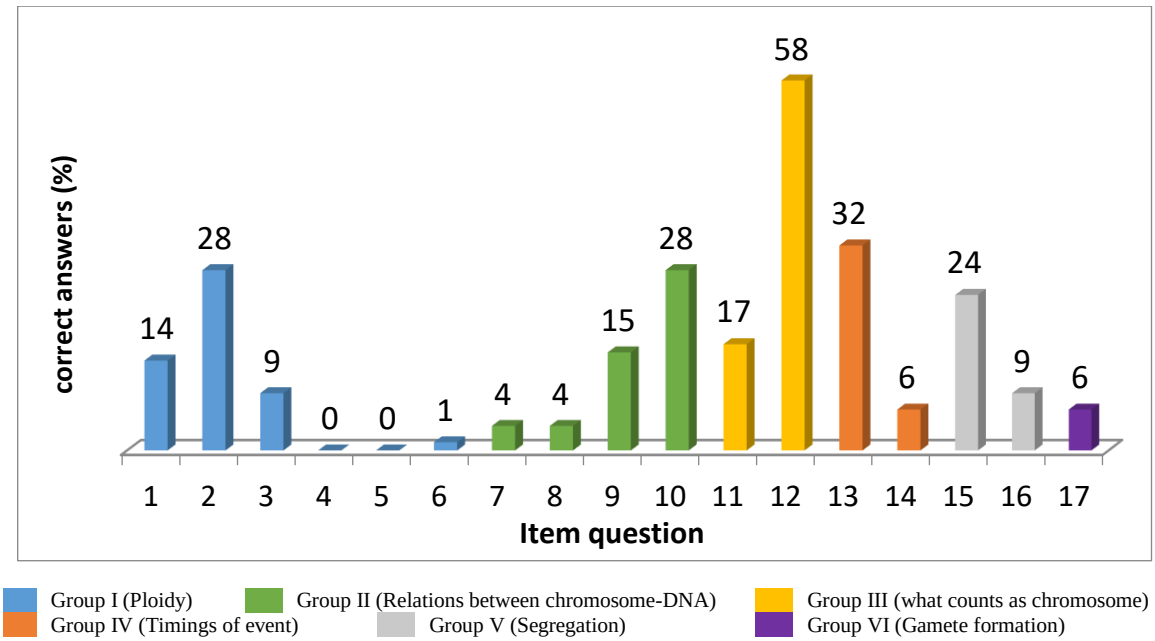


Figure 4. 16 Proportion of correct responses to MCI test given by Year 3 Biology Education students at Universitas Tanjungpura in the academic year of 2016/2017 (n=78). *MCI test was given to investigate the understanding of meiosis concept to the general population of students who had taken genetics module in the previous semester. Colour on the diagram showed the division of the group of MCI questions*

Figure 4.16 showed that this group of biology education students have a low understanding of the concepts relating to meiosis following their completion of their genetics module. Less than 10% students responded correctly to seven questions (number 3, 6, 7, 8, 11, 14, 16 and 17). None of students gave correct answers for questions 4 and 5. Only one question (number 12) was answered correctly by more than 50% of students. Compared to students of the same programme in the previous academic year (see Figure 4.7), this cohort have a similar pattern of the concept understanding of meiosis. The differences were located on the higher frequency in responding to question 12 (13% higher), and lower correct responses for question 2, 13 and 16 (a decrease of 14%, 16%, and 15% respectively).

Table 4. 11 The percentage of incorrect answers per item question of MCI and the possible identified common misconception of meiosis for Biology Education students at Universitas Tanjungpura in academic year of 2016/2017 (n=78).

MCI was given to Biology education students toward their completion of Genetics module. Students received no learning intervention with the meiosis video. Concept on column (1) refers to the group of questions advised by Kalas et al., (2013). Column (2) refers to the number of question in the MCI test. Column (3) shows the theme of question for each number. Column (4) shows the percentage of students who gave incorrect responses per question MCI. Column (5) gives the interpretation to the possible common misconceptions derived from the largest proportion of students giving the incorrect responses who chose certain incorrect option or combination of options of MCI test. Concept: I = Ploidy; II = Relations between chromosome and DNA, III = what counts as chromosome; IV = timings of event; V= segregation; VI = gamete formation
(*) questions which evaluate two or more concepts: no.2 (ploidy-chromosome-replication), no.6 (ploidy-chromosome-alleles), no. 13 (DNA-replication-phase), no.17 (ploidy-phase-alleles)

Concept	**No**	**Topic of questions**	**Incorrect responses (%)**	**Possible common misconceptions explained from students' responses**	
(1)	**(2)**	**(3)**	**(4)**	**(5)**	
I	1	the **definition** of **haploid**	85.9	81%	Haploid cells have half number as many chromosomes than diploid cells
	2*	representation of **2n=6 before replication**	71.8	70%	In a diploid cell, what counts as chromosome is one duplicated chromosome ("X")
				21%	In a diploid cell, what counts as chromosome is one duplicated chromosome ("X"), before replication number of "X" were half of those after the event (replication increase the number of chromosome)
	3	the **notation** of triploid cell (chromosome="X")	91.0	80%	Duplicated chromosome ("X") symbolises a diploid cell, the cell notation 2n=6
	4	the pictorial representation of **haploid** cell	100.0	62%	A haploid cell is identified from contains unduplicated chromosome ("I")
	5	identifying the representation of **diploid** cell	100.0	59%	A diploid cell is identified from contains duplicated chromosome ("X")
				10%	A diploid cell is identified from contains an even number of duplicated chromosome ("X")
	6*	somatic cell **2n=2, AaBbDd**	98.7	27%	Somatic cell is identified from having a paired duplicated chromosome ("X"), in one chromosome: AbD-another aBd (correct representation of sister chromatids)
				35%	To include Somatic cell is identified from having two unpaired duplicated chromosome ("X"), distribution: AaBb vs Dd (incorrect representation of sister chromatids)
II	7	Identifying what **"X" symbolises**	96.2	37%	To include an idea that "X" symbolises diploid chromosome
				41%	To include an idea that "X" symbolises a pair of homologous chromosome

	8	Predicting the consequence of **DNA replication**	96.2	51% 40%	To include an idea that replication increases the number of chromosomes To include an idea that replication increases cell ploidy (e.g. from 2n→4n)
	9	Identifying how **DNA molecule is represented in "X"**	84.6	55% 38%	To include an idea that an "X" represents one double stranded DNA molecule To include an idea that an "X" represents two single stranded DNA molecule
	10	identifying cell(s) which share the same **number of double stranded DNA molecule**	71.8	73%	To include an idea that a duplicated chromosome ("X") have the same number of double stranded DNA molecules as its unduplicated form ("I")
III	11	identifying cell(s) with certain **number of chromosomes**	83.3	25% 26%	One chromosome is counted as one chromatid One chromosome is counted as one unduplicated chromosome ("I")
	12	counting **number of chromosomes** of a cell	42.3	85%	One chromosome is counted as one unduplicated chromosome ("I")
IV	13 *	Identifying **cell in stage(s) of meiosis** that share **the same amount of DNA** with that cell before replication	67.9	55% 23%	The amount of DNA in a cell before replication = at prophase meiosis 1, suggesting that replication happen at prophase 1 The amount of DNA in a cell before replication = at prophase meiosis 1, suggesting that replication cell segregate at metaphase 1
	14	Identifying event(s) happen at **prophase 1**	93.6	49%	To include an idea that DNA replication happens at prophase 1
V	15	Identifying to what occasion the diagram showing **a segregation between sister chromatids** contains different alleles may exist	75.6	29% 54%	Considering this event happen at meiosis 1, suggesting the confusion between events of meiosis 1 and 2 Considering this event happen at mitosis, suggesting the confusion between meiosis and mitosis
	16	Identifying what stage of meiosis for a representation of **chromosome lining** up at equatorial cell	91	30% 32% 27%	Considering the event happen at meiosis 2, suggesting the confusion between events of meiosis 1 and 2 Considering the event happen at mitosis, suggesting the confusion between mitosis and meiosis Considering the event happen at metaphase 2/mitosis, suggesting the confusion between mitosis and meiosis
VI	17 *	Identifying cell that represents **gamete from meiosis of a cell (2n=4, AaRr)**	93.6	41% 22%	Considering gamete as a 2n=4 cell contains unduplicated chromosome, suggesting the confusion gamete with daughter cell of mitosis Considering gamete as any cells containing half of chromatids, either counted as unduplicated chromosome or as duplicated chromosome

Table 4.11 shows that students have a very low understanding to the subordinate concepts of meiosis, particularly for ploidy (number 3, 4, 5, and 6). Many students considered ploidy based on the structure of the chromosome rather than by counting chromosome pairs. This erroneous idea was very clear when students were asked to distinguish haploid from diploid cells (question 4 and 5). The limited understanding affected students in visualising triploid cell (question 3), and in answering complex questions involving the concept of ploidy (question 6 and 7). Another difficult subordinate concept was related to understand what counts as chromosome (questions 11 and 12). The low understanding of those two subordinate concepts was similar to the findings of previous cohort (IND-1). However, the lower percentage of correct response to question 16 (segregation) suggested that this cohort may have a more serious problems in relation to understanding meiosis.

4.8.2. Impact of the meiosis video and follow-up activity: IND-2

The evaluation of the impact of the meiosis video and follow-up activity in addressing students' understanding of meiosis was conducted with a voluntary group of students from the IND-2 cohort (2016/2017, n=19). The effectiveness of the resource was assessed by any concept changes revealed by students' responses to the MCI test (Appendix B-3) and from the interview. Students' perceptions on how the resources engaged them in learning the concept of meiosis (through interview and observation) were also considered in the resource evaluation.

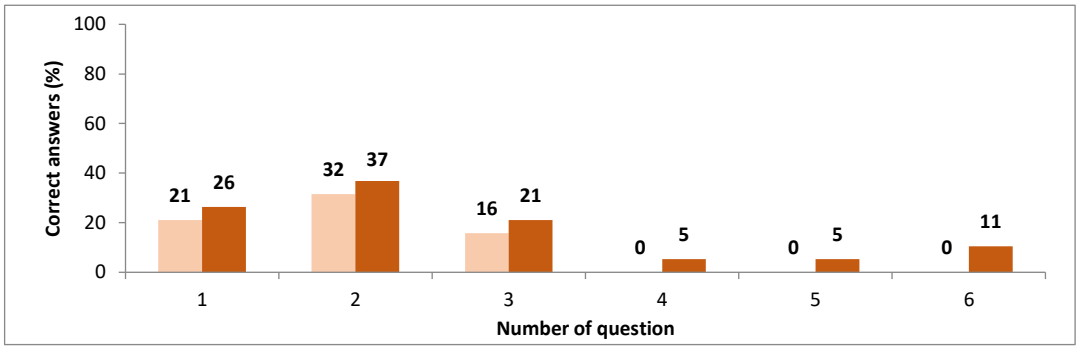
In general, there were clear trends of improvements on students' correct response to the MCI after watching the meiosis video and conducting the follow-up activity (Figure 4.17). Significant improvements (increase of ≥20%) were identified for counting number of chromosomes (Group III) and deciding the phase of meiosis involved in segregation (Group V). A smaller improvement of MCI score (<20%) was identified for identifying ploidy and differences between chromosomes, chromatids and homologous pairs (Group I), describing relations between chromosome and DNA (Group II), and determining genotype of gamete (Group VI). The only type of question showing a decrease in correct answers was Group IV (timings) with no correct answers for question 14.

The trend of the improvement of MCI score was slightly different from the first cohort (IND-1) when only the meiosis video was introduced to try and combat students' misconceptions of meiosis. Although there are similar trends in the improvement on

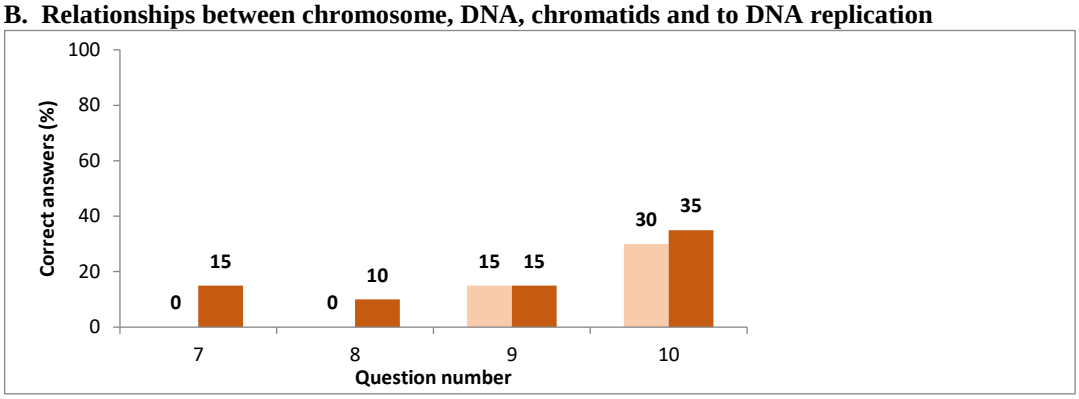
counting number of chromosome (Group III) and on deciding phases of meiosis involved in segregation (Group V), the increase in correct scores for identifying cell which has certain number of chromosomes (question 11) and identification of cell showing metaphase 1 (question 16) were higher in this cohort. In addition, an improvement on the visualisation of haploid and diploid cells, and the identification of the structure constructed a duplicated chromosome ("X") was observed. However, in this cohort (IND-2), no student could identify events related to prophase I correctly (question 14).

Further breakdown analysis of correct answers in the MCI post-test (Figure 4.18) shows that the largest improvement (changed from incorrect to correct) were for questions 16 (55%), 11 and 15 (each of 40%). Other questions had a correct score improvement ranging from 5-25%. There were four questions that have different pattern of improvement of those of IND-1 cohort (questions 4, 5, 6 and 7). will be the focus to try and understand which factors within the new presentation of the meiosis video contributed to promote this improvement.

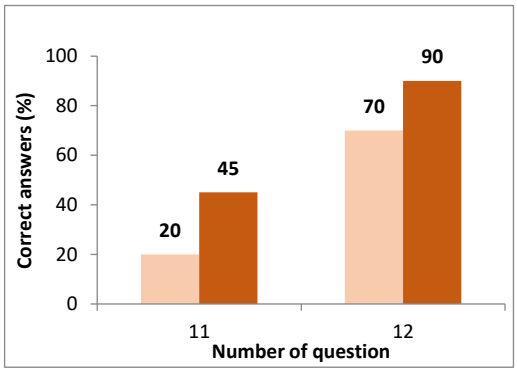
A. Ploidy; differences between chromosomes, chromatids and homologous pairs



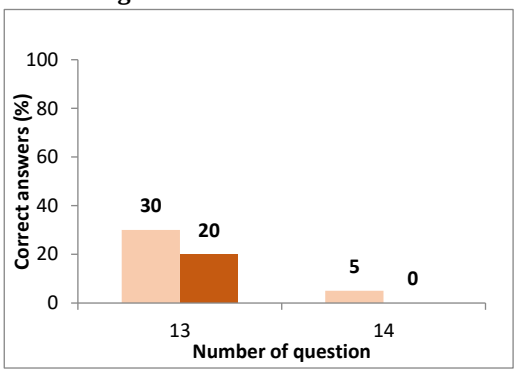
B. Relationships between chromosome, DNA, chromatids and to DNA replication



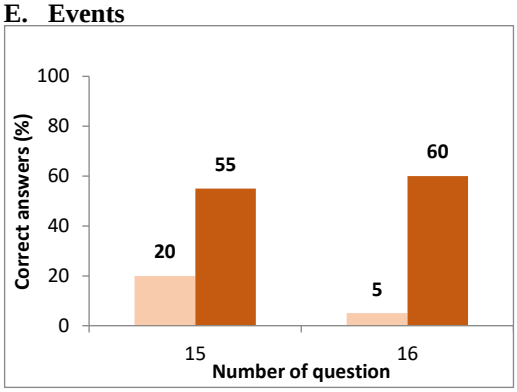
C. Chromosome



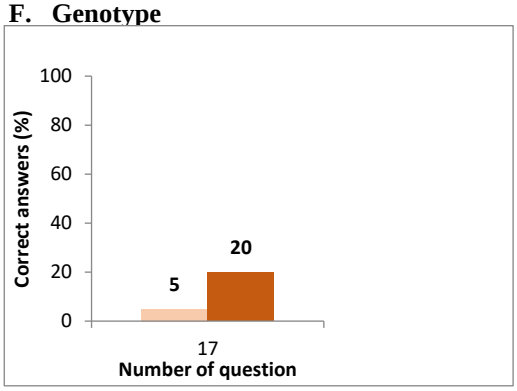
D. Timings



E. Events



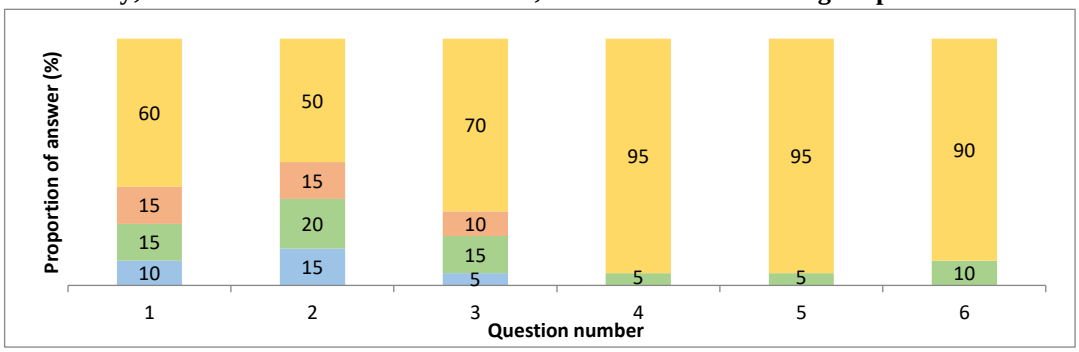
F. Genotype



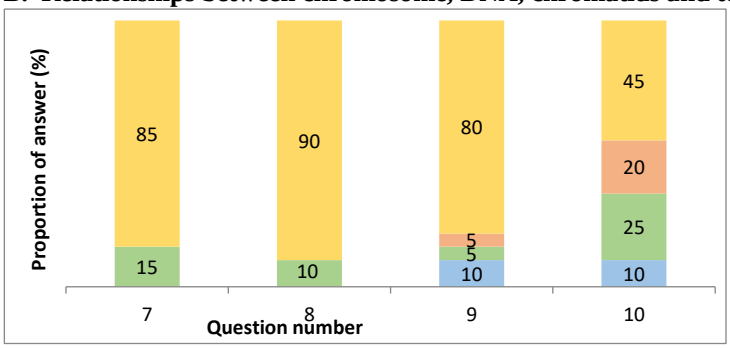
Pre-test Post-test

Figure 4. 17. A comparison between correct answer of MCI test before (pre) and after (post) watching the video for IND-2 group of participants (n=19). *The figure showed the comparison based on the group of question. MCI post-test was given after learning session with meiosis video and doing activity. A large improvement was observed on number 11, 15, and 16.*

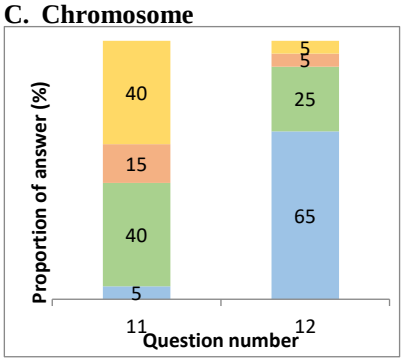
A. Ploidy; differences between chromosomes, chromatids and homologous pairs



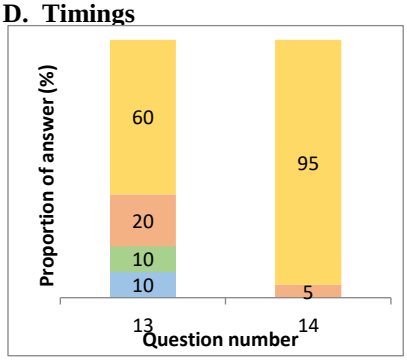
B. Relationships between chromosome, DNA, chromatids and to DNA replication



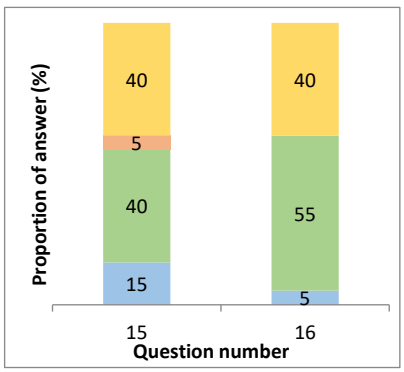
C. Chromosome



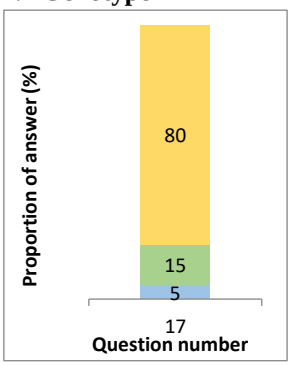
D. Timings



E. Events



F. Genotype



Remain incorrect answer | CHANGE to incorrect answer | CHANGE to correct answer | Remain correct answer

Figure 4. 18. A comparison between type of changes on the answer of MCI test before (pre) and after (post) watching the video for IND-2 group of participants (n=19). *The types of changes on the answer were presented based on the group of question. Post-test of MCI was given right after learning session with meiosis video. (Notes: The percentage shown here was rounded up/down to the closest number automatically by Excel program, which may not result in 100% in total if each part was summed up).*

Similar to the IND-1 cohort in the first evaluation, this cohort (IND-2) also showed an improved understanding of the stages of meiosis, particularly for identifying metaphase 1 (characterised by the pair up of chromosomes, question 16 of the MCI) and anaphase 2 (characterised by different alleles on sister chromatids, question 15 of the MCI). However, when students were presented with a different representation (using a picture of plasticine-model of chromosome) in the interview, not all students could identify these phases.

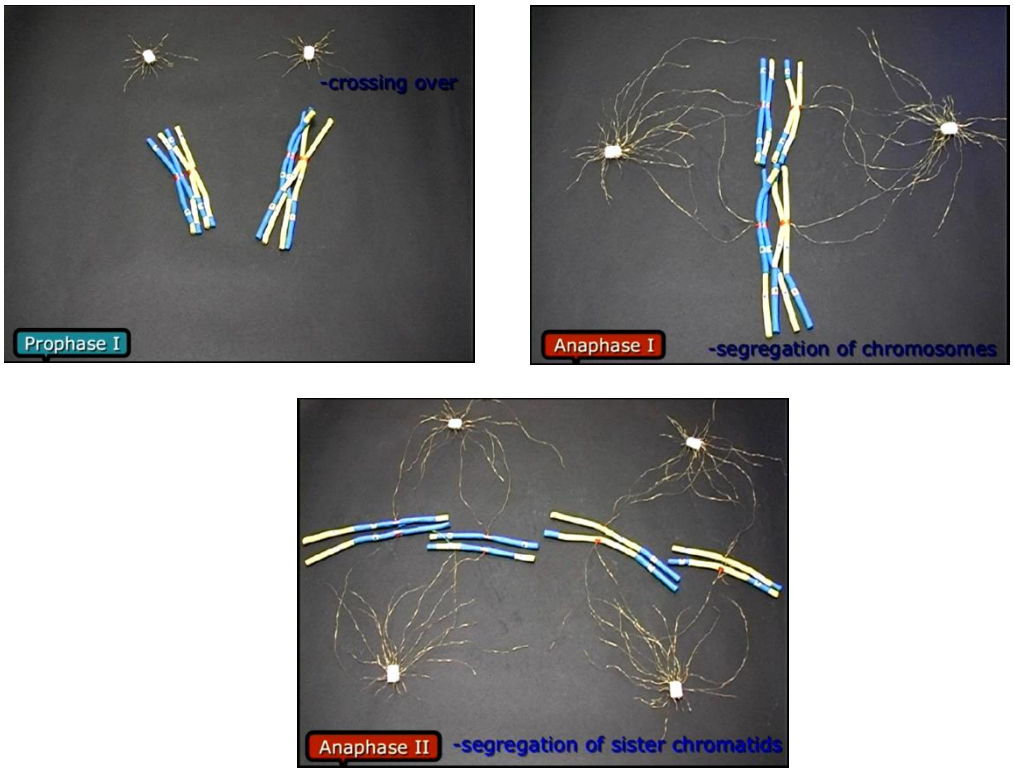


Figure 4. 19 Three scenes of the video represented recombined (crossed over) chromosomes leading to students' confusion on recalling the stage of crossing over and chromosomes segregation. *Students thought crossing over occurred at anaphase 1 rather than prophase 1, since the chromosomes are still paired up and attach on chiasma. Students confused between anaphase 1 and 2 for identifying the two events based on having recombined parts (crossed over) on the chromosome. Top left: Crossing over at Prophase 1; Top right: segregation of chromosomes at anaphase 1; below: segregation of chromatids at anaphase 2.*

Two out of 11 students who correctly identified metaphase 1 on the MCI post-test, could not do so again when presented with the picture during the interview. One student (Azmi) mistakenly identified an event at metaphase 1 *"*[chromosomes] *are lined up on the middle* [of the cell], *have been crossed over, and still in pair between paternal and maternal chromosomes*" as event at metaphase 2 (Azmi/Interview2/18 December 2016) indicating that he did not have solid idea of events in meiosis 1. Another student

(Dina) confused event at metaphase 1 with metaphase 2. She believed that crossing-over (genetic recombination) happen at anaphase 1, thus the crossed over chromosomes in the middle of the cell referred to metaphase 2. She supported her answer by referring to a segment in the video showing segregation process which produced different colours (crossed over) chromosome at anaphase 1 (see Figure 4.19 for a reference of this segment). The same problem of thinking crossing over occurs at anaphase 1 shown by Aliya and Karina. The two students have a problem distinguishing prophase 1 from anaphase 1. Students having misinterpretation of crossing over occurs at anaphase 1 did not realised that the event actually occurs at prophase 1, however, chromosomes still attached to each other until they segregate in anaphase (Hochwagen, 2008), although it was clearly cued or labelled in the video.

Another significant improvement was on the understanding of what counts as chromosome. While students in the IND-1 cohort showed only a slight improvement with this concept, students in the IND-2 cohort showed good progress in understanding the idea which is shown by 40% change into correct conception for number 11 (see Figure 4.18). IND-2 students did not only successfully count the correct number of chromosomes in a given cell (chromosomes are presented as duplicated (X) form, question 12), but also successfully identified cells contains a certain number of chromosomes (chromosomes are presented as unduplicated (I) and duplicated (X) chromosomes, question 11). This clearly showed that students understood that chromosomes could be in either unduplicated or duplicated form. This progress could be related to the simulation activity which enables students to observe and count the chromosomes both in unduplicated and duplicated forms, which may have introduced this idea better than just watching the video.

Although understanding of the concept of ploidy still problematic, a better understanding of the concept of ploidy was shown by Laila, as evidenced by her correct answers to most MCI questions related to ploidy (questions 2, 3, 4, 5), apart from one asking about definition of haploid (question 1). However, having a correct definition of haploid does not necessarily guarantee to have an accurate understanding of the representation of ploidy (as shown by Faiza, Hana and Vira).

Correcting misunderstanding of ploidy was hard to achieve. This was evidenced as none of the IND-1 students (previous cohort) had identified it correctly in MCI questions 4 and 5. Introducing the follow-up activity in the second evaluation clearly had a positive effect on students' understanding, as evidenced by Laila's case.

Although Laila showed that doing the follow-up activity helped her to understand the concept of ploidy, this was not seen for all students. In their worksheets, all groups of students could identify the cell ploidy in different stages of meiosis correctly. However, only five students (including Laila) use the pairing between paternal and maternal chromosomes to identify diploid cell in the interview. Among these five, only Laila could identify representation of diploid cell correctly in the MCI test, while the other four showed an incorrect understanding of how ploidy in the cell is represented.

Looking back to Laila's case, the re-conceptualisation of ploidy was obtained from observing the terminology part of the meiosis video and observing the paper model of chromosomes during the simulation. She claimed that video helped her to conceptualise a diploid cell. Although in her interview, she referred the diploid cell as the 'diploid chromosome' but she gave a correct representation of diploid cell.

> *"… after the replay* [terminology part of video] *I became clearer. There is a set of 'diploid chromosome', consist of paternal and maternal. In the beginning, I confused, why it is considered as a set, while they are on different colours. Uhm… I think "what is one set? What is diploid?" and all sorts of things. So, when someone asked to replay the video and I watching it again, I become understand why it is called diploid, because it consists of paternal and maternal. Why the colours are differentiated, that's because for easiness… And then when crossing over takes place, why it* [a chromosome] *consists of two colours, and then… ah, that's because it has been crossed over."* (Laila/interview2/17 December 2016).

She confirmed her new understanding of ploidy with the researcher while doing the simulation activity (Observation notes/06 December 2016). She confirmed her new understanding of haploid as a set of chromosomes when she observed chromosome segregation at anaphase 1 and finally when the haploid gametes are produced through her simulation. She explained her experience in getting new understanding of concept of ploidy in her interview.

> *"Which one is considered as one set of chromosomes, when and how meiosis 1 takes place, and when and how meiosis 2 takes place, and what is the final result, I finally understood. Both video and activity are of the same contributing value. If it is only video, we just watch. Maybe it works for the audio-visual learners. But, if we need to understand the concept beforehand, well, just watching probably will take longer time* [to understand the concept]. *But, with the simulation, hands-on simulated activity with stickers, I do understand. Which one is paternal chromosomes, …"* (Laila/interview2/17 December 2016).

Her learning activities in developing an understanding of the concept of haploid, which initially came from the understanding of homologous pairing between paternal and maternal chromosomes, suggests to explicitly presenting the haploid concept using a group (set) of paternal or maternal chromosomes in the parent cell (at the beginning of

meiosis), and later showing the set of chromosomes in a gamete as an example of haploid cell. This step is considered to be useful in combatting the misunderstanding or misrepresentation of gamete from the video (see section 4.8.4).

Another useful way to introduce the correct concept of ploidy was to be thought to familiarise students with the concept of triploid. Students were typically informed with the concept of diploid (parent cell) and haploid (gamete cell) cells when they learn meiosis. This was evident in the many commonly used textbooks in biology and genetics (e.g. Klug *et al.*, 2016; Raven 2000) as well as depicted in many studies on conceptualising meiosis which emphasised on the understanding of ploidy (e.g. Chinnici, 2006; Wright and Newman, 2011; Heineman, 2017). However, focusing only on these two terms of ploidy may mislead students to relate the concept of haploid and diploid with the presentation of unduplicated and duplicated chromosomes consecutively. Adding a concept of triploid means that students add another set of chromosomes into a diploid cell which will help them to reorient their focus from considering ploidy as the form of chromosomes into ploidy as the set(s) of chromosomes. Although a triploid cell is not naturally occurred in meiosis, but this additional information may be inserted in the video while students learn the concept of ploidy.

4.8.3. Misconceptions during follow-up activity: IND-2

The follow-up activity was originally designed to assist students to overcome their misconceptions of meiosis. However, it also revealed students' misconceptions with homologous chromosomes and chromosome structure, which had not been anticipated initially.

Students were asked to construct the chromosome model by sticking rectangular labels to demonstrate loci and circular label to locate centromere. At first, they were given the model of unduplicated paternal and maternal chromosomes symbolising cell before replication (cell at G1 of interphase). They were required to put all chromosome models on the table while counting them before demonstrating the replication process. However, some groups constructed bizarre chromosome model which joined in the paternal and maternal chromosomes on the centromere, even though they were not matched as a pair (Observation notes/06 December 2016). Figure 4.20 shows the reconstruction from students' misconceptions to the idea of pairing between paternal and maternal chromosomes.

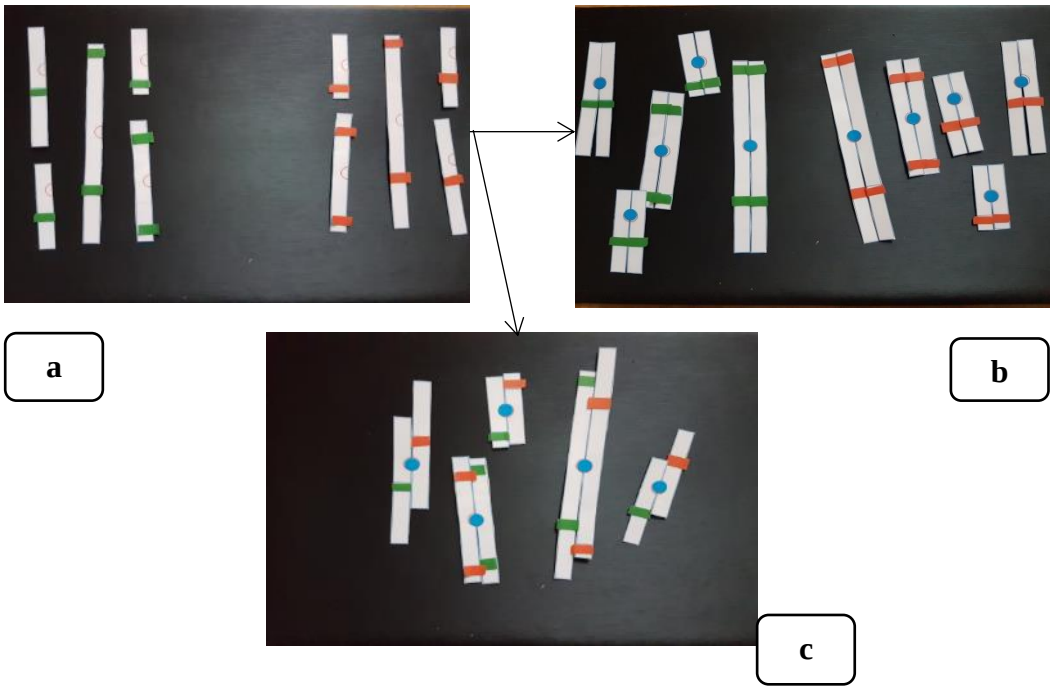


Figure 4. 20 Reconstruction of IND-2 students' incorrect representation of paper model of chromosomes. *(a) Representation of unduplicated paternal (green) and maternal (red) chromosomes which was given in the beginning of simulation activity. (b) Expected model of duplicated paternal and maternal and chromosomes. (c)Incorrect model built by students to produce duplicated chromosome by combining paternal and maternal chromosomes (shown as the mismatch between the chromatids). Blue dot symbolised the centromere.*

This step was highly stimulated by the idea that all chromosomes should be in duplicated form ("X" form) to be considered as one. Roni showed his group bias conception of chromosomes in his excerpt.

> *"Roni: I thought, when they* [the models] *were given, uhm, I thought, uhm…When they were given, I do not understand about alleles, maternal and paternal chromosomes, so I just crossed* [joined] *them together*
>
> *In : So, did you do that randomly, or did you gave any reason to join them together?*
>
> *Roni: I have this idea, that they were there to be joined. Because I thought that they have been crossed* [mating], *so I did that.*
>
> (Roni/interview2/18 December 2016)

He and his group had the correct definition of paternal and maternal chromosomes. However, his idea of mating was incorrect. The intention to join paternal and maternal together, as shown in Figure 4.20, was informed by his understanding that a chromosome should be always be in a duplicated form. However, the group's

misconceived idea was challenged by the instruction which required them to simulate replication by sticking the replica (sister chromatid) to each chromosome. His friend confirmed their difficulty in his interview excerpt.

> *"I was confused. We were not solid. Dani had put the centromere sticker, and Roni stick the chromosomes together, and they were joined. They [Dani and Roni] did not read the instruction. It said to uh,. the "parental" and then "marental", and then stick others. We got confused [because of what the two students do]. We could not continue"* (Omar/interview2/19 December 2016)

This problem was not only experienced by this group, other groups showed the similar confusion, however they corrected their idea before taking the step shown by Roni's group.

It was clear that the students' puzzled idea regarding building the models was valuable to challenge their misconceptions of structure of chromosome (homologous chromosomes/sister chromatids, and what counts as chromosome) and correct them accordingly. However, as most groups showed that they needed more guidance to revise this concept, it is suggested to include a confirmation step after building the chromosome model (by means of class review) before continuing the simulation.

4.8.4. Resistant misconceptions of meiosis: IND-2

Further analysis of interview and observation data revealed the following students' misconceptions, some of them is believed to be perpetuated by the video and/or follow-up activity:

1. Relationship between DNA and chromosome

The relationship between DNA and chromosome is one of the ideas introduced in the video. However, some students showed misinterpretation of the concepts. These erroneous ideas can be categorised into three groups:

1) A molecule of DNA refers to nucleotides

When students were asked to count the number of DNA molecules per chromosome, it was clear that some (three out of 19) thought that there are countless DNA molecules per chromosome, as they wrongly believed the question was referring to nucleotides.

> *"… on a chromosome, there are many DNA double helix…" (Aliya/interview2/18 December 2016)*

> *"Because it [a chromosome], a molecule of DNA, is rolled up…to make a strand. So, it is difficult to count" (Dani/interview2/19 December 2016)*

> *"… molecules of DNA are numerous, they are countless" (Gandhes/interview2/18 December 2016)*

2) One locus (gene) refers to one DNA molecule

Some other students (three out of 19) had the idea that one gene is constituted by one molecule of DNA. Since there was no scene of the video leading to this error idea, their misunderstanding is highly likely to stem from before watching the meiosis video, leading them to misinterpret the information presented. More information on this will be discussed in Chapter 6.

> *"If I am not mistaken, I saw* [on the video] *that on one arm of chromosome, there is one strand of DNA. Because these are sister chromatids, so DNA here is the same with this one… so, there are 1, 2, … there are 8 DNA"* **(**Bona/interview2/18 December 2016)
>
> *"DNA molecule is located on the genes inside the chromosome. So.. from this picture, there are several symbols which showed traits carried by the genes inside the chromosome. So, looking at the symbols, there are six, uhm, six traits. So, there are six, six molecules of DNA… 1, big A, 2, big G, 3, little g, 4 little b, 5, uhm big E, 6, big D, uhm, 7, ah… it is 7 little d"* (Laila/interview2/17 December 2016)
>
> *"Inside one locus is one DNA, DNA is located inside a locus. Thus, all of these* [pointing at alleles] *are DNA"* (Raras/interview2/20 December 2016)

3) One paternal or maternal chromosome refers to one DNA.

The erroneous idea that in meiosis the chromosomes from the father and mother combine, so that each chromosome consists of two molecules of DNA led to the incorrect thinking that each of the parental chromosomes is one DNA molecule.

> *"… [this picture showed] two molecules of DNA, one from each parent"* (Ika/interview2/17 December 2016)

2. Mistaken idea of ploidy: Different concepts of gamete

1) 'Haploid chromosome'

The idea of considering haploid as 'a chromosome' rather than 'a cell' was revealed during students' interviews (see Figure 4.21).

> *Ra: … meiosis 2 will produce 4 daughter cells. The four daughter cells are these* [pointed at the picture], *or, (silent) or this [picture] is one of them?*
> *In: What do you think? Which one is the correct one as a gamete?*
> *Ra: I understand that as one of these* [pointed at one chromosome]
> (Raras/interview2/20 December 2016)

2) 'Haploid is a combination of paternal and maternal'

Another common misconception was that students believed that any structure containing paternal and maternal genetic material was considered a haploid gamete (see Figure 4. 21). In this case, students incorrectly came to this conclusion led by the idea that a gamete has half genetic material from father and another half from mother. They misinterpreted the idea to see a gamete as a cell which has a combined part of paternal and maternal chromosomes.

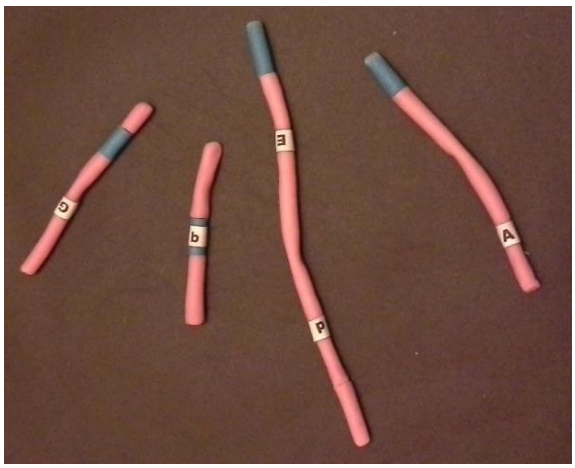


Figure 4. 21 A representation of four chromosomes of one gamete. *This picture was presented to students in their interview. Students misconceived the idea of gamete and considered gametes to be chromosomes or any structure of combined paternal and material genetic material.*

4.8.5. IND-2 Students' perception to the video illustrating meiosis and follow-up activity

It is important to measure students' perception of any teaching tool in order to further develop the tools (Gagné, 2005). As demonstrated with students in the previous cohort (IND-1), students' engagement with the meiosis video was assessed through analysing students' behaviour during the video and follow-up simulated meiosis using the paper chromosome models.

At the beginning of the video, students in the front row gave it their full attention, while students in the back row still talked to each other. They stopped talking when the video entered the scene showing mechanism of meiosis (Observation notes/06 December 2016). Students' talking clearly distracted other students who wished to see and hear the explanation from the video, as admitted by Omar (see Table 4.12, column 3, row 7). However, this may also suggest that students were not interested in watching the meiosis in the first play, possibly by thinking that the video offered an explanation using the same approach as other material they had already known. However, they find it different from other teaching materials of meiosis they had seen when they watched

the process explanation of meiosis (see Table 4.12, column 3, row 4). From the interview, it is found that the parts of the video that showed chromosome movement attracted many students' attention because of different reasons, such as interesting models and activating curiosity (Table 4.12, column 3, row 3). Because of the distraction, students asked to play the introduction part which explained terminologies one more time. Some other students actually asked to repeat the second and the third parts of the video, but majority did not want to do so thinking the considerable time they would have to spend to watch all parts again (Observation notes/06 December 2016). Repeating the terminology part gave positive impact for revising concept, such as claimed by Laila (Table 4.12, column 5, and row 6). The presentation of concept of ploidy on the first play of the video initialised questions for Laila, for example 'what constitutes a set of chromosomes'? She clarified her understanding of this during the replay. The request for giving students access to video playback control was part of student feedback (Table 4.12, column 4, row 18).

Students were interested in watching the video for many reasons, all of which could be related to promoting their understanding of the concepts of meiosis. The most common feedback was on the clear presentation of process of meiosis (9 out of 19 students). In the interview students revealed that the visualisation of meiosis had helped them to re-visualise the concept of meiosis. In addition, Bona pointed out that the video had helped her to get a better understanding of meiosis because of the chronological explanation and synchronous presentation of visual concepts and narration (Bona/interview2/18 December 2016). The educational video also presented an approach of explaining meiosis that was different from videos and textbooks available in the Indonesian language (Table 4.12, column 3, row 4).

The most useful part of the meiosis video was the terminology part, as acknowledged by 6 out of 19 students. These students revised their concepts on what counts as a chromosome, and consequently correctly identified the number of chromosomes (as shown by the improvement MCI scores for questions 11 and 12). One student, Laila, revised her concept of ploidy based on viewing the introduction-terminology part (Table 4.12, column 5, row 6).

The follow-up activity was also considered as a valuable resource to learn meiosis. Laila mentioned that both watching the video and doing the follow-up activity had the same value to help her revise the concepts of ploidy, as she mentioned in the interview:

> *"Which one considered as a set of chromosomes, when and what meiosis 1 produce, and what would happen after meiosis 2, I become understand.* [Watching] *video is as valuable as* [doing] *the activity. If it is only video, I could only see. Maybe it works for those who are visual or audio-visual learners. But, understanding only from video will take time. By simulating with stickers, I do understand, which is determined as paternal chromosome".* (Laila/interview2/17 December 2016)

Other students (7 out of 19) emphasised the importance of this activity as a source to justify their concept of meiosis. Dina gave an example on how she justified the concept of counting number of chromosomes she saw on the video into through filling out table which asked for identifying number of chromosomes in the worksheet.

To maximise its impact, some students thought that the video could still be improved with respect to adjusting the speed of narration and display (2 out of 19), and the clarity of showing how alleles (genotypes) are arranged during different stages of meiosis (1 out of 19). Unlike the first cohort (IND-1), only two students thought that the pace of the video was too fast. Since students in this cohort (IND-2) were better prepared (having been alerting to the follow-up activity and having had the terminology part of the video repeated), it confirmed that the fast display and narration, mentioned by the IND-1 cohort, and the two IND-2 students, was most likely due to an overloading of working memory (Chu and Reid, 2012). The latter obstructed learning by reducing students' learning capacity to take in new information from the video. Students who had misconceptions of basic concepts will use their working memory faster in order to revise their misunderstandings before continuing to learn. Two students (out of 19) suggested that their concept learning using the video was negatively influenced by the time of the day and distraction by other students. Other suggestions were related to repeating the video or giving students access to the video in their own time.

Although students liked the follow-up activity, most of them (9 out of 19) showed initial difficulties in constructing the chromosome models, and therefore suggested assistance in that construction process (3 out of 19). However, as mentioned in the section 4.8.3, the difficulty of constructing the chromosome models also gave the advantage of revealing students' further misconceptions of homologous chromosomes. Thus, as an instrument to identify misconceptions, the model construction should be retained as part of this activity, with a clear, reworded instruction.

Table 4. 12 A resume of IND-2 students' perception to the meiosis video (n=19). *A theme of students' perception is presented on column (1). Students' views were coding from the interview (column 2). An example from the interview excerpt is presented on column (3)*

Resource	Theme	Classifications	Description	Example of students' excerpt of interview
(1)	(2)	(3)	(4)	(5)
Video	Advantage of the video	Concepts visualisation	Process of meiosis [9]	*"... to facilitate the understanding of how chromosomes are divided* [segregated] *during meiosis division "* (Azmi/interview2/18 December 2016)
			Retention image of meiosis [5]	*" .. because I am a visual learner ... it is easier to explain meiosis 1 and 2. I could still see what I saw* [on the video]*"* (Dani/interview2/19 December 2016)
			Chronological explanation [1]	*"...* [it] *facilitated learning basic concepts of chromosomes, since the video, since the first part, gave the definition, and symbols and terminologies*" (Bona/interview2/18 December 2016)
		Facilitation of concepts understanding:	Chromosome structure [5]	*What I still remember is the terminologies. I used to know that this one and that one* [sister chromatids] *are different, even though they were joined, but it also called a chromosome.* (Hana/interview2/17 December 2016)
			Variation [2]	*"... in crossing over, paternal and maternal chromosomes are crossed over ... the new combination will be on several chromosomes ...to produce a new chromosome variation"* (Dani/interview2/19 December 2016)
			Ploidy [1]	*"...In the beginning, I confused, why it is considered as a set ...I become understand why it is called diploid, because it consists of paternal and maternal. ..."* (Laila/interview2/17 December 2016)
		Engagement:	Exciting models [5]	*" ... anaphase ... when they* [chromosomes] *are aligned and will go to different poles, they look so interesting, because they are moving..."* (Omar/interview2/19 December 2016)
			Slow pace [2]	*"... and the video is not too fast, has a slowmotion and explanation, thus make me easy to understand"* (Bona/interview2/18 December 2016)
			Curiosity [1]	*"Everything is interesting ... from the selection of media, the pictures, they make me feel uhm, became curious, want*

				to know … what it would become" (Ika/interview2/17 December 2016)
			Inspiring [1]	*"… We were given a task for genetics module, we want to make something like the video, it seems interesting, simple to make, but easy to understand …"* (Hana/interview2/17 December 2016)
		Different presentation to the typical learning media of meiosis:	Different from text-book [3]	*" … there was an explanation on symbols … on the textbooks the explanation on symbols are not complete, only for chromosomes that already condensed"* (Bona/interview2/18 December 2016)
			Different from other videos [1]	*"On other videos … the models of chromosomes are different … in this video, the movement are slower, and model of chromosomes are clearer … So, all* [chromosome] *movement on every steps are clearer* (Vira/interview2/16 December 2016)
			Using local language [1]	*"[I like it] because it was on Indonesian language … that makes me interested in* [watching] *the video at the first time"* (Dina/interview2/17 December 2016)
	Limitation of the video	Limited presentation	Alleles arrangement during meiosis was not clear [1]	*"The alleles swap and the [allele] combination afterwards, that is I think what I did not get from watching the video"* (Dina/interview2/17 December 2016)
			Fast narration [1] Fast display on last part [1]	*"The explanation* [narration] *too fast … whether she talks fast, or I could not catch her explanation"* (Roni/interview2/18 December 2016)
		Content	Too many information [2]	*"I like the video. It is simple, and understandable. But, uhm, it is difficult to remember all of the concepts presented, I do not know why … "* (Gandhes/interview2/18 December 2016)
	Suggestion to revise the video	Supporting environment	Creating supporting environment when playing the video [2]	*"I would like to suggest that everybody is quiet when the video is playing. I could not hear the first part, and finally made it but when it almost at the end"* (Omar/interview2/19 December 2016)
		Video playing	More than one play [4]	*"if I just saw it once, I did not understand. I have to watch more than one time"* (Sammy/interview2/20 December 2016)
			Separated sections play [1]	*"I hope video will be played step-by-step, started from*

				prophase, and all… let us clear first about what is prophase, terminologies related to prophase, and then continue to metaphase" (Laila/interview2/17 December 2016)
Follow-up Activity	Advantage of the follow up activity	Promoting cooperation	Learning in groups [2]	*" … doing it* [activity] *with friends, so we can shares. If I do not know, my friends explained it to me … so, I get more understanding"* (Mimi/interview2/18 December 2016)
		Applicative	Applicative: Real simulation [4]/Applied from video [3]	*"If we directly do it* [hands-on]*, we know it better. …So, I think it is effective, compared to we just get a theoretical explanation* [lecturing]*"* (Raras/interview2/20 December 2016)
		Clarity	Most useful: Table [1]/Ploidy concept [1]	*"… the thing that I think it is reinforcing my knowledge. We have to do the table [on the worksheet], counting number of chromosomes before and after duplication, so I confirmed my friends many times about how we got the number…"* (Dina/interview2/17 December 2016)
		Engagement	Attractive representation: Exciting [1]/Interactive [1]	*"it* [paper model] *is a real object to study chromosomes* [movement] *and not only through the video"* (Gandhes/interview2/18 December 2016)
	Disadvantage of the follow up activity	Difficulty in building the model	Difficult in constructing chromosome [9]	*"We made a mistake in the beginning, we thought they* [paternal and maternal chromosomes] *are from two haploid cells, … but we actually required just to moving between one cell"* (Karina/interview2/20 December 2016)
			Coins [3]	*"…in the part where we required to use coin, … what is the function of coin actually. I do not understand till now"* (Dina/interview2/17 December 2016)
	Suggestions to revise follow up activity	Instruction	Direct instruction – chromosome construction [3]	*"Maybe we should be given an introduction explanation, for example how to use the cards* [paper model of chromosomes] *and how we applied what we saw on video to this representation"* (Roni/interview2/18 December 2016)

4.9. Evaluation of the impact of the meiosis video and follow-up activity on students' understanding: UK

An equivalent evaluation of the educational video of meiosis and the follow-up activity was conducted with a group of biology/biomedical undergraduate students at University of Leicester. Despite of limited number of participants (n=2), this case is useful to enhance the plausibility of using the educational resources with students who had been taught meiosis in a different way. Unlike the Indonesian case where meiosis was taught as part of cell division and was given the same amount of teaching time as that of mitosis (Candramila, 2016), students in the UK case had been taught the concept of meiosis in many alternative ways. The importance of understanding meiosis in generating genetic diversity, inheritance, and evolution had been realised by the University of Leicester instructors, and had been implemented teaching meiosis using various different approaches, including the use of the MCI test to track students' confusion and specific hands-on activities (Kramer, 2017).

For this cohort, the impact of the meiosis video and its follow-up simulation activity were evaluated through observation of how students take advantage of the resources and the interview to reveal their understanding of meiosis concepts.

4.9.1. Impact of the meiosis video and follow-up activity: UK

The impact of the video and conducting the follow-up activity was measured by evaluating any misconceptions that students still have after a learning session with the resources based on their MCI test (Table 4.13). Their understanding of meiosis was validated with their responses to the similar questions given in the interview. The engagement with the resources was assessed through their perception on the resources in the interview and was validated with the observation made during the resources trial.

Students were given the MCI test after watching video and conducting the simulation. In general, the two UK students answered most of the MCI questions correctly (11 out of 17). There were five questions (1, 3, 4, 5, and 14) which could not be answered correctly by Charles; four of these were related to the incorrect concept of ploidy (see Table 4.13). Both students gave incorrect responses to question 6, which asked about the representation of certain genotype in a somatic cell. These findings suggest that this cohort may still lack a thorough understanding of ploidy and the concepts of homologous pairing for a somatic cell.

Table 4. 13 The possible explanation of common misconceptions of meiosis from incorrect responses of MCI test for UK case following watching meiosis video (n=2).

MCI was given to UK students after completed watching the video and doing the following simulation activity. Concept on column (1) refers to the group of questions advised by Kalas et al., (2013). Column (2) refers to the number of questions in the MCI test. Column (3) shows the theme of question for each number. Column (4) shows the percentage of students who gave incorrect responses per question MCI. Column (5) gives the interpretation to the possible common misconceptions derived from the largest proportion of students giving the incorrect responses who chose certain incorrect option or combination of options of MCI test.
The table showed only possible common misconceptions derived from students' incorrect answers of MCI. All students' correct answer does not show on the table.
Concept: I = Ploidy; II = Relations between chromosome and DNA, III = what counts as chromosome; IV = timings of event; V= segregation; VI = gamete formation
(*) questions which evaluate two or more concepts: no.2 (ploidy-chromosome-replication), no.6 (ploidy-chromosome-alleles), no. 13 (DNA-replication-phase), no.17 (ploidy-phase-alleles)

Concept (1)	No (2)	Topic of questions (3)	Incorrect responses (%) (4)	Possible common misconceptions explained from students' responses (5)	
I	1	the **definition** of **haploid**	50%	50%	Haploid cells have half number as many chromosomes in diploid cells
	3	Choosing the **notation** of a triploid cell	50%	50%	Duplicated chromosome ("X") symbolises a diploid cell, the cell notation 2n=6
	4	Identifying pictorial representation of **haploid** cell	50%	50%	A haploid cell is identified from a cell that contains unduplicated chromosome ("I") and have an odd number of chromosomes
	5	Identifying of the representation of **diploid** cell	50%	50%	A diploid cell is identified from cell contains even number of chromosomes
	6*	Identifying somatic cell **2n=2, AaBbDd**	100%	50%	Somatic cell is identified from having all dominant alleles on one chromosome and all recessive alleles on its homologous chromosome
				50%	Chromosomes in somatic cell could be in pair or not in-pair
IV	14	Identifying event(s) happen at **prophase 1**	50%	50%	DNA replication happens at prophase 1

4.9.2. UK Students' perception to the video illustrating meiosis and follow-up activity

Students in the UK case gave positive responses to both video and follow up activity (Table 4.14). The use of clay chromosome models was the most advantage aspect of the video, due to the fact that it is familiar, "[something] *you have been used to* [seeing] *before"* (Noah/interview2/2 June 2017). Moreover, they thought the application of model chromosomes in an animated 3D video was beneficial to visualise the process of meiosis, particularly in identifying the transition between phases and observing how crossing over occurs.

Both UK students were able to correctly simulate meiosis in the following up activity (Observation notes/3 May 2017). For Charles the activity clarified his understanding about the concept of loci. Noah appreciated the use of the paper chromosome models as this gave him a better understanding to the process of meiosis, particularly in identifying at what stage of meiosis variation in the gametes was generated. For him, the simulation activity was interesting as it provided a more motivating hands-on experience and the opportunity to observe how meiosis works, at his own learning pace.

The video and the follow-up activity were designed as interrelated educational resources and therefore they were used accordingly in learning the concept of meiosis. Noah particularly liked the idea of presenting the terminology part of the video followed by the simulation activity, while Charles suggested using the same chromosome models for both the video and the simulation activity.

Table 4. 14 A resume of UK students' perception to the meiosis video (n=2). *Themes of students' perception is presented on column 2. Students' views were coding from the interview (column 4). An example from the interview excerpt is presented on column 5.*

Resource	Theme	Classifications	Description	Example of students' excerpt of interview
(1)	(2)	(3)	(4)	(5)
Video	Advantage of the video	Concepts visualisation	Visualisation of Process [1]	"*…model of chromosome is helpful, visualisation is always helpful… interesting to see different phases, it is more interesting than being told the definition*" (Charles/interview2/2 June 2017)
			Visualisation of Crossing Over [1]	*" .. it was interesting to see CO with the clay-mation. It helped to show CO, in a more direct way."* (Noah/interview2/2 June 2017)
		Facilitation of concepts understanding:	Useful model [2]	"*I have seen different version of models of chromosomes, such as drawing, clay models, imaging. So, I use different pictures when I talk about chromosome, but part of it is the model that I have seen on the video*" (Charles/interview2/2 June 2017)
				"*It is a good thing to use that. 3D, it's unique and a good way to imagine the chromosome. The concept is easier to understand because it uses clay that you have been used before*" (Noah/interview2/2 June 2017)
	Limitation of the video	Limited presentation	Fast display [1]	"*the video s good, but the language lots of jargon for genetics, it went by so quick. So, when you think about one thing, you may miss the next bit. It may be good but need to show couple of times."* (Noah/interview2/2 June 2017)
Simulation Activity	Advantage of the follow up activity	Applicative	Concept verification [2]	"*... teaches of variation side of meiosis and separation stage of chromosome and stages where the variation comes from*" (Noah/interview2/2 June 2017) *"…how they fit together, and you have been told about the loci, but it is different from doing that yourself…"* (Charles/interview2/2 June 2017)
			Moving model [1]	"*…favourite part of the activity would be … the aspect that we stick sticker on the chromosome. It is a more … unique way to representing it* [chromosome] *... As opposed to the card, you got the drawing of the chromosome and next card has different drawing, you should have to imagine what happen in between. But with this model of chromosome you can move it apart, physically, … So I think I like that aspect of it, the fact that chromosomes are cut out…*" (Noah/interview2/2 June 2017)
			Adjustable pace [1]	"*… Whilst the activity can be done on our own pace ... So, if you miss something you can review that on your own pace. and Do It Yourself"* (Noah/interview2/2 June 2017)
Video & Activity	Suggestions to revise	Better models of chromosome	Using clay model [1]	"*They* [clay and paper model of chromosomes] *are both ... I guess an alternative. If I actually got to use, say different models* [of chromosome], *then I would go to use them [clay models]. And actually, by using them together, and if we could stick on the loci like this, actually have them and press them into the playdoh, so you would not have to tear them of sticker…* (Charles/interview2/2 June 2017)
		Simultaneous use	Using both video and activity [1]	"*…for the beginner of meiosis, it might be worth to show just the terminologies part of the video, and not the rest of it. Showing slowly and couple of times*" (Noah/interview2/2 June 2017)

4.10. Reflection on the second cycle of the development of meiosis video and recommendation

The revision on the presentation of the meiosis video from the first cycle was expected to promote better students' understanding of the concept of meiosis, particularly on revising concept of ploidy and structure of chromosome. However, analysis showed that students (IND-2) still had difficulty in understanding the concept of ploidy and structure of chromosomes as of students in the first case (IND-1). Of these two concepts, concept of ploidy was harder to change, with only one student experiencing a concept change, conforming a thought of Wright and Newman (2011) that the ploidy is the most difficult concept to understand in learning meiosis. A bigger impact on concept change on ploidy was hoped to achieve by highlighting the concept of ploidy as 'number of set of chromosomes' by introducing a visualisation of a triploid cell in the video. As discussed in section 4.8.2 (on page 60), this understanding prevents students from visualising a diploid cell as a cell having duplicated chromosomes at the beginning of meiosis and from visualising haploid cell as having unduplicated chromosomes at the end of the process. Applying specific cues in the video (Tabbers, *et al*., 2004) to highlight the fact that each daughter cell of meiosis 1 is a haploid cell may also prevent the idea that every haploid cell is a cell with the unduplicated chromosomes.

The fact that all group participants (IND-1, IND-2 and UK) gave positive comments about the meiosis video and the hands-on follow-up simulation activity showed that video and the task could engage students' attention to learn meiosis, as revealed in their interviews. The additional follow-up activity was claimed by students to further enhanced the changes of students' concept of meiosis. The introduction of the activity to accompany watching the video provided an advantage by revealing the misconception which were not detected by only using test and interview, as shown in section 4.8.3. However, the presentation of the task should be made simpler as many participants felt that the instruction was hard to follow, creating unnecessary cognitive effort to understand the instruction. This has been described by Sweller and Chandler (1991) as the extraneous cognitive load. Future revision of the resource will involve a simplification of the task which present a step-by-step simulation process of meiosis using the worksheet.

As for the video, the problem was a very few students were able to fully grasp the whole story of how meiosis generates genetic diversity. Many students were still struggling with understanding the subordinate concepts. Based on the research, it is

important to give students more time to watch the first part of the video and to do the additional simulation activity afterward. The uninterrupted explanation of process of meiosis on the video and the simulation of process of meiosis by performing additional activity created the simpler learning task by promoting the ability to understand the material as suggested by Kalyuga et al., (2003). Therefore, the future presentation of the resource should first focus on revising students' concept of meiosis through reconstructing their idea of subordinate concepts and the process of meiosis by showing the first part of the video only followed by the simulation. The second focus should be revising the students' concept of how meiosis contributes to generating genetic diversity, by showing the second and third part of the video.

Chapter 5 – Revising students' understanding of Mendelian inheritance through inheritance cards activity

Overview

This chapter provides the reader with a thorough description of the development process of inheritance cards in a worksheet of inheritance and the follow-up evaluation of the resource. From here onwards, throughout this thesis, this inheritance cards and all related worksheet of inheritance will also be referred to as the ***'inheritance cards activity'***. It begins with the rationalisation for developing the card game and is followed by description of the development process. It continues with a discussion of how the resource influences students in an Indonesian case (IND-2) in improving their understanding of Mendelian inheritance through learning with the cards. A counterpart case with UK students is presented after the first case. The chapter will be concluded with reflections and recommendations from conducting this study.

5.1 Rationale for creating Inheritance cards activity

Mendelian genetics (also known as Mendelian inheritance or single gene inheritance) is one of the fundamental concepts in genetics. The central part of this topic is indicated by the coverage of this topic in all higher education genetics textbooks (e.g. Elrod, Susan and Stansfield, 2007; Hartl and Jones, 2005; Klug *et al*, 2016; Brown, 1992; Brown, 2012; Pierce, 2010) as well as in biology textbook (e.g. Raven and Johnson, 2002; Reece *et al*, 2014). Topic in Higher Education genetics courses always cover Mendelian inheritance, despite the differences of the genetics curriculum approach adopted. Mendel first approach where genetics starts with discussing classical genetics (Griffiths and Mayer-Smith, 2000), or the inverted approach which begins the subject by presenting the common complex trait rather than the single character as in Mendelian Inheritance (Dougherty, 2010). Mendelian inheritance also is fundamental topic discussed in secondary school biology in Indonesia as well as in the UK. These are mandated in the national syllabus for both countries, the 2013 curriculum syllabus for secondary school (age 13-15) of Indonesia (Notodiputro, 2013b) as well as for high school (age 16-18) (Notodiputro, 2013a); and the syllabus for sixth form colleges (age 16-18) in the UK (e.g. (OCR, 2013)). Furthermore, the fundamental position of learning Mendelian genetics showed by various researches on genetics education regards to this topic (e.g. (Williams *et al*, 2012; Williams, Montgomery and Manokore, 2012; Lewis and Wood-Robinson, 2000; Winsor, 1988).

Hartl *et al*., (2014) summarised Mendelian genetics as "*the mechanism of inheritance in which the statistical relations between the distribution of traits in*

successive generations result from (1) particulate hereditary determinants (genes), (2) random union of gametes, and (3) segregation of unchanged hereditary determinants in the reproductive cells" (p.553). A set of characteristics of Mendelian genetics is explained in the literature as follow. Mendelian genetics is known as transmission genetics for it deliberates the description of how a trait of interest could be passed from one generation to the next. The factor or heredity element (gene, in modern terms) is the vehicle for the transmission. Mendel was the first to show that a gene is transmitted as a preserved discrete material. Thus, the morphological or observable trait in the offspring, is specified by the same factor that determine the trait of its parents. In Mendelian genetics, heredity factors come in two forms (alleles, in modern term), the dominant and recessive alleles. These factors are segregated during the formation of gametes (reproductive cell), so that each gamete will only contain only one allele. When fertilisation ("*the union of the two gametes*", King, Mulligan and Stansfield, 2013, p.166) occurs, an allele of a trait from the male parent will combine with its counterpart from the female parent, which then specify the trait of an offspring. This is explained as Mendel's first law, the principle of segregation. A factor that specifies one trait is transmitted independently to other traits. In a case where the two observable traits are inherited together (dihybrid cross), allelic segregation of each trait is independent, and thus does not interfere with each other. The segregation of alleles of one trait do not interfere the allelic segregation of other traits. This is conceptualised as Mendel's second law, the principle of independent assortment (Elrod, Susan and Stansfield, 2007; Hartl, 2014; Klug *et al*, 2016; Lewis, 2015).

The two principles of Mendel are parallel with gametogenesis, "*the formation of gametes*" (King, Mulligan and Stansfield, 2013). Gametogenesis occurs through the meiotic process. Mendel's segregation refers to the chromosome segregation in anaphase 1, while the independent assortment reflects the random attachment of spindle fibres during metaphase 1 (Brown, 1990). For that reason, Klug *et al.*, (2016) considered understanding chromosome behaviour in meiosis as a key concept in understanding Mendelian inheritance. The integration between concepts of meiosis and Mendelian inheritance was also suggested by (Wynne, Stewart and Passmore, 2001; Knipples, 2002; Allen and Moll, 1986).

Teaching Mendelian inheritance which focuses more on solving mathematical problems (probability) using a Punnett square diagram was argued as the reason for many students tend to memorise steps in mathematical solution, than to understanding

the process of how an individual or a cell passes their genes to offspring (Knipples, 2005). Consistent to Knipples' idea, Mill-Shaw (2008) showed that 80% errors about pattern of inheritance on the DNA national essay contest in the USA was made because students have less conceptual understanding regards of the topic, but instead apply simple Mendelian inheritance analysis via Punnett square. For example, students could not link monosomy with the abnormal mechanism of meiosis in their essay. Stewart (1982) explained that teaching understanding of Mendelian genetics based on solving mathematical problem (the probabilities)) caused students to solve a monohybrid cross (involving the principle of segregation) with a lack of understanding of the reason for their manipulation of symbols in Punnet squares. In this sense, they have a low concept understanding of Mendelian inheritance. Nusantari (2011) showed the low understanding of meiosis and Mendelian inheritance led Indonesian students to misconceive the segregation process (Mendel's first law) only occurs on monohybrid crosses (crosses involving one specific trait), whilst independent assortment (Mendel's second law) performs only on dihybrid cross (crosses involving two specific traits). The same result was confirmed to exist among Biology student teacher at Universitas Tanjungpura in the academic year of 2013/2014 (Maulidi, Mardiyyaningsih and Ariyati, 2015). Thus, although there are other factors contribute to the understanding of Mendelian Inheritance, for example problems in understanding probability (Honeycutt and Pierce, 2007), or in understanding the correct term of dominance (Allchin, 2000), the literatures suggests that the problem relating meiosis and Mendelian inheritance is the key factor to help students obtaining a correct concept of Mendelian inheritance.

The integration of meiosis into the teaching of Mendelian inheritance had been proposed by (Allen and Moll, 1986). They had proposed the problem solving of inheritance activity which asked students to solve actual problems of inheritance by visualising sequence stage of meiosis. In so doing, students would link Mendelian genetics with meiosis (and mitosis) and the molecular events of protein synthesis. (Wynne, Stewart and Passmore, 2001) integrated meiosis and Mendelian inheritance through changing the instructional design of highschool course (age 16-18) in the USA. They provided the edited version of Mendel's work which followed by Sutton's work to help students see the connection between Mendelian inheritance and meiosis. Both studies showed that students have a better understanding of Mendelian inheritance which was indicated by an increase of test score (in the first case) and the ability to

recognise and analyse anomalous data of inheritance using the concept of meiosis (in the second case).

Both of the studies referred to above showed the effectiveness of integrating meiosis into the teaching of Mendelian inheritance. However, in both studies of Allen & Moll (1986) and Wynne, Stewart and Passmore (2001), meiosis was not physically visualised, but was presented as a mental process that students use when they solve Mendelian inheritance problem. Students who have a poor understanding of meiosis may have difficulty in seeing the connection of this process to Mendelian inheritance. Therefore, showing the physical visualisation of meiosis is expected to help students to link meiosis and Mendelian inheritance. As showed on section 4.2 in this thesis, a deep understanding of meiosis had been limited because of numeorus misconceptions (e.g. (Kindfield, 1994; Lewis and Wood-Robinson, 2000)). To promote students' understanding of meiosis, Dr Nicola Suter-Giorgini of GENIE-CETL, University of Leicester (2010) had developed a card-based tutorial to visualise concept of meiosis in creating genetic diversity, resulting in an increase in student understanding of the process and terminology of meiosis (further details could be obtained on VGEC website of University of Leicester). According to the author, the card-based activity was based on a simple set of rules which enabled other educators to create extended activities based on their instructional needs. In this sense, the understanding of meiosis could be promoted by visualising its process on cards. This led to the idea of combining the presentation of meiosis concept on cards with the events of fertilisation which is crucial in crosses in Mendelian inheritance as an alternative way to support student in making a link between Mendelian inheritance with meiosis.

5.2 Specific methods to the development of the inheritance cards activity

The general methods for the development of inheritance cards activity followed the sequence of action research in developing targeted educational resources (see Chapter 3 section 3.1). This section is dedicated to explaining detail procedure which was different from the development of other resources in this thesis.

5.2.1 Mapping research questions with methods

Specific research questions for the development of inheritance cards activity were derived from the general research questions for this thesis (see Chapter 1, section 1. 3).

Table 5.1 maps methods adopted in the development to the specific research questions. The use of two or more data sources showed the data triangulation method.

Table 5. 1 Mapping research questions with types of data used to study the effectiveness of the inheritance cards activity

Research questions	Source of data			
	MCI Test	**Observation**	**Interview**	**Researcher journal**
RQ 1. How is information regarding common misconceptions used to develop the inheritance cards activity?				√
RQ 2. What are university students' existing perceptions of the basic concepts of Mendelian inheritance?	√			
RQ 3. In what ways does the inheritance cards activity modify university students' misconceptions of Mendelian inheritance?				
RQ 3.1. What misconceptions are altered after use of inheritance cards activity?	√		√	
RQ 3.2. What elements of inheritance cards activity contribute to the change?		√	√	√
RQ 3.3. How do university students perceive their learning experience with the inheritance cards activity?		√	√	
RQ 4. Are there any differences in the way university students in Indonesia and the United Kingdom perceive the benefits of inheritance cards activity?	√	√	√	

5.2.2 Design of study for developing inheritance cards activity

The procedure used to develop the inheritance cards activity followed the general methods for developing targeted resources as presented in Chapter 3 section 3.2. This study involved evaluation of the resource by two groups of students, IND-2 and UK (Figure 5.1). The timeline for the development of this targeted teaching resource was presented in Figure 5.2. Due to time constraint to evaluate the revision of the inheritance cards activity in the second cycle, this study consisted only one cycle of the development involving IND-2 and UK participants to evaluate the first version of the cards' activity. This chapter will be concluded with the recommendation for improving the way of using the inheritance card activity.

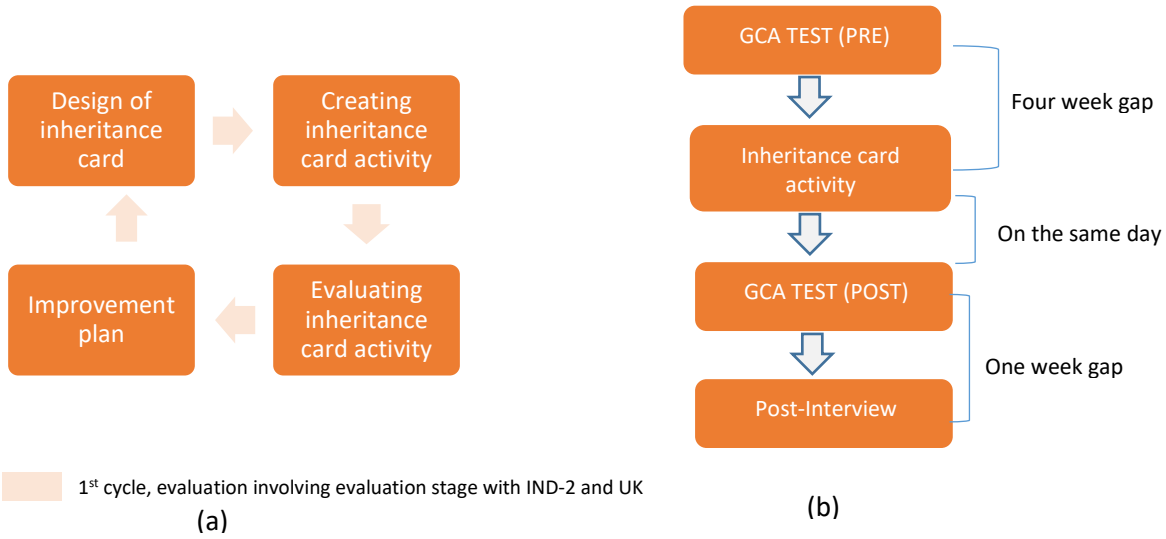


Figure 5. 1 A summary of research design and a sequence of evaluation of inheritance card activity. *(a) study research design (one cycle). Evaluation of inheritance cards involved IND-2 and UK cohort (b) a flow of evaluation stage for each cohort showing the activity they do related to the method of data collection (test, observation, and interview)*

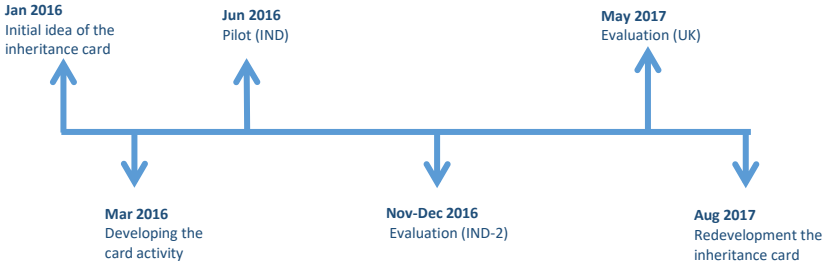


Figure 5. 2 Research timeline showing important stage in the development of the inheritance card activity

5.2.3 The context of study and participants

This study follows the four stages of action research for developing resources. In the first two stages (design and develop), researcher designed and created the inheritance cards activity. The development sequence of the resource was recorded. In the next stage (evaluation), the effectiveness of the inheritance cards activity in addressing misconceptions regards to the Mendelian inheritance was measured through different sources (methods). In the final stage (reflection), researcher reflected on the three previous stages to the potential benefit of the inheritance cards activity in supporting students learning Mendelian inheritance.

Students at both participant groups involved in this study (IND-2 and UK) were at the stage of completing the genetics instruction at the time of this work (see Chapter 3 section 3.3 for detail characteristic of each group). A selection of questions, from the

Genetics Concept Assessment (GCA), were given for the total population of students taking genetics module in the same academic year of the IND-2 group (see detail of GCA test on section 5.2.4). This was done at the beginning of evaluation stage, before the inheritance cards were implemented. The collected data illustrated the general level of understanding of Mendelian inheritance amongst Indonesian students participated in this study. After the pre-testing with the GCA, IND-2 participants were invited to informal teaching session to use the inheritance cards. Students' interaction with the card resource were observed during the session and notes were recorded. Post-testing using the GCA was given after the implementation sesion. Within a week, students were interviewed about their learning experience with the cards. Only data from students who had completed all stages in the evaluation of the cards were included in the analysis. This was due to the need for data triangulation. UK participants were not given the pre and post test of GCA since the test was integrated in their genetics module. Table 5.2 shows in detail the number of students involved in this study from each group of students. The sequence of evaluation of inheritance cards with IND-2 and UK groups is presented in Table 5.3.

Table 5. 2 Number of participants involved in the evaluation stage of cards of inheritance

Group	Academic year	Number of participants for		
		Pre-testing GCA	Try-out the inheritance cards	Completing all evaluation stage
IND-2	2016/2017	75	25	17
UK	2016/2017	-	2	2

Table 5. 3 Data collection timetable for the evaluation of the inheritance card activity

Stage	Date	Activities
1st	**INDONESIA CYCLE 1 (IND-2)**	
	15 Nov 16	Part of GCA Test (PRE)
	14-15 Dec 16	Teaching session/observation to students' interaction with the inheritance card activity
	14-15 Dec 16	Part of GCA Test (POST)
	16-20 Dec 16	Interview
	UK	
	03 May 17	Teaching session/observation to students' interaction with the video resource
	02 Jun 17	Interview

5.2.4 Data collection, analysis and interpretation

In general, the data collection, analysis and interpretation for this project followed the thesis methods in collecting and analysis data described in Chapter 3 section 3.5 and

3.6. This section is dedicated to give a more detail explanation to specific data collection and analysis relating to the specific testing and interviews used to evaluate this resource.

Data collection

The Genetic Concept Assessment (GCA) is a validated test which designed to "*evaluate the effectiveness of teaching reforms in different sub disciplines of the life sciences, including genetics*" (Smith, Michelle, Wood and Knight, 2008 p.422), as well as to "*document common conceptual difficulties in genetics*" (Smith, M. K. and Knight, 2012, p. 22). There were 25 multiple-choice (MC) questions on GCA. Table 5.4 shows questions topics for the 25 GCA MC questions. The table was adopted from the "*Course learning goals for the CU majors in genetics course and corresponding questions on the GCA*" and is unaltered from Smith et al., (2008, p.423) to give an idea of the coverage of the test. Students were given a complete GCA test, however, only selected GCA questions that related to Mendelian Inheritance (see Table 5.4 column 3) were analysed. The selection was made based on the suitability of the concepts in questions with the inheritance cards activity. Two of the selected questions (number 3 and 10) were categorised as MCIA (most common incorrect answer) according to investigation by Smith & Knight (2012) to their 751 year-1-undergraduate students enrolled in six genetics courses at University of Colorado. In analysing the test, they divided GCA questions into three categories: (1) no difficulties, if 80% or more students answered questions correctly; (2) no single incorrect idea, if less than 80% of students answered the questions correctly, but no single option was chosen by at least 20% of students; (3) incorrect idea, if less than 80% of students answered the question correctly, and 20% or more students chose one single option. Students who repeatedly choose the same incorrect answers on MCIA questions were indicated to have misconceptions.

The GCA test was distributed as paper and pencil test for this project. Students were given one minute to answer each question which gave a total of 25 minutes to do all items. All question booklets were collected back together with the answer sheet. The question booklets were destroyed after the post-test to ensure the confidentiality of the test. While doing the test, students were asked to write their names on the answer sheet. This was important due to the need to compare students' answers before and after the teaching session with the cards. However, no names of student who participated in this project are included in the findings and discussion. In places where there is a need to

mention a name, student is referred to by their pseudonym, to ensure the confidentiality of students as detailed on the section on ethics (section 3.7).

Table 5. 4. Selected part of the GCA test which tested students' understanding of concepts relating to Mendelian Inheritance. *Column (1) and (2) are referred to "*Course learning goals for the *CU majors genetics course and corresponding questions on the GCA" (adopted as it was written on* (Smith, Michelle K., Wood and Knight, 2008)*). Column (3) shows the selected GCA questions which were further analysed to reveal students' understanding of Mendelian Inheritance in this study*

Course learning goal* (1)	Question no. [a]* (2)	Selected questions for the study (3)
1. Analyze phenotypic data and deduce patterns of inheritance from family histories	1, 11, 13	13
2. Describe the molecular anatomy of genes and genomes	9, 10, 15, 24	10, 24
3. Describe the mechanisms by which an organism's genome is passed on to the next generation	7, 8, 16, 17, 25	-
4. Describe the phenomenon of linkage and how it affects assortment of alleles during meiosis	21, 23	23
5. Extract information about genes, alleles, and gene functions by analyzing the progeny from genetic crosses	4, 14, 18	18
6. Describe the processes that can affect the frequency of phenotypes in a population over time	3, 12	3
7. Compare different types of mutations and describe how each can affect genes and the corresponding mRNAs and proteins	2, 5, 6, 22	2
8. Apply the results of molecular genetic studies in model organisms to understanding aspects of human genetics and genetic diseases	20	-
9. Interpret results from molecular analyses to determine the inheritance patterns and identities of human genes that can mutate to cause disease	19	-

[a] The learning goals associated with each question are those intended by the authors. These associations are supported by expert responses but have not been further verified through student interviews or other means (as it written on Smith, Wood, and Knight (2008, p.423))

* The column which was adopted from Smith, Wood, and Knight (2008, p.423)

The interview was designed to be conducted within a week of the teaching session with the resource. Students' understandings were elicited through the discussion with a diagram showing an illustration of a dihybrid cross of two individuals with a certain genetic disorder (albinism and brachydactylic). Both conditions were transmitted to the offspring following the Mendelian Inheritance pattern of autosomal recessive and autosomal dominant pattern (Cummings, 2006).

Data analysis

Students' answers were marked using provided model answers. An overview of students' general understanding of Mendelian inheritance was obtained by counting the percentage of correct responses for each selected question. Participants' correct

responses to GCA before (pre-test) and after (post-test) were calculated to give an overall understanding of the influence of inheritance cards in assisting students' understanding to solve problems related to Mendelian inheritance.

After IND-2 cohort responses to GCA before (pre-test) and after (post-test) were marked, for each question, individual students' responses to GCA before and after are compared to reveal whether students gave: (1) remaining correct, (2) remaining incorrect, (3) change to correct, or (4) change to incorrect answer. The interpretation of students' revision of misconception/misunderstanding questions relating to Mendelian inheritance was validated through triangulation with data from students' response in interviews.

The possible identified misconceptions derived from their answers were analysed based on their chosen option. The interpretation of students' revision of misconception in meiosis from analysis of the GCA test was validated through triangulation of data from students' interview responses.

5.3 The design and creation of the inheritance cards activity

This section discusses the initial design and construction of the card resource. The design stage focused on determining the instructional purpose of the inheritance card, analysing targeted common misconceptions that would be dealt with, and planning the presentation of the card. The construction stage focused on creating the inheritance card and related task-activity.

5.3.1. The design of inheritance cards activity

The initial idea of designing an activity using inheritance cards came from the intention to visualise the relationship between Mendelian Inheritance with steps in meiosis. Thomas Hunt Morgan (1866–1945) and his team had showed that the heredity factor was actually the linearly arranged discrete part of chromosome (Allen, 2003). The principles of Mendelian inheritance involved in producing gamete reflect the chromosome's behaviour during meiosis. Following the success of improving undergraduate students understanding of meiosis using The Meiosis Card activity (Suter-Giorgini, 2010), a series of stages in meiosis were represented as a sequence of cards. The important features of Mendelian inheritance are summarised by (Stewart and Kirk, 1990, p.578) as follow:

> "*1) chromosomes, genes and alleles occur in pairs; 2) at least two alleles exist for a gene; 3) a pair of alleles codes for a particular variation for a trait; 4) the two alleles may pair in one of three ways—1,1; 2,2; 1,2; 5) these three combinations of alleles map to phenotype in one of two ways—either the 1,2 genotype is the same phenotype as one of the other allele pairs or it has a unique phenotype. In the first case, then, there will be two distinct phenotypes, while, in the second there will be three. Beyond these basics, it is only necessary to understand that there is a mechanism (meiosis) that is responsible for separating allele pairs and a second (fertilization) that is responsible for uniting the separated parental pairs. Together, these two processes produce new genotype combinations and thus new phenotypes. Common genetics concepts such as simple dominance, multiple alleles, and codominance are ways of describing how pairs of alleles interact to produce variations of traits*"

The heredity factor on chromosomes was presented as two alleles on the chromosome (Stewart and Kirk, 1990; Kindfield, 1994). Labelling alleles with genotype symbols during meiosis allow students to tracking how alleles are segregated and reunited to determine traits of the descendants. This had been demonstrated in an activity of creating "Reboops" (Heineman, 2017; Dewees, Maresco and Parente, 2006), as well as it parallel digital version being a "Dragon" (Horwitz *et al*, 2010). In these two activities, a descendant of physical fictitious animal (reboops and dragon) was created based on phenotype determined by the genotype shuffling performed by students. Fertilisation is shown by physically mating the two gametes, each from father and mother. This idea of showing physical mating was adopted in the development of the inheritance cards.

The idea of representing alleles on chromosomes also provided the opportunity to introduce the autosomal and sex chromosomes leading to the demonstration of different patterns of autosomal recessive, the autosomal dominant and the sex-linked (X and Y) inheritance (Cummings, 2006). Since Mendelian inheritance is typically related to the use of Punnet square (Batzli *et al*, 2014), the explicit relation between Mendelian inheritance and meiosis could be represented as the use of the Punnett Square altogether with the meiosis cards. Punnet square could also beneficial to record the gamete probabilities and gamete shuffling during fertilisation.

Instruction for using the cards and the Punnett square were devised as problem which required the students to predict the offspring from parents that have certain conditions. This acted as a trigger for students to think of solving Mendelian inheritance through visualising steps in meiosis as suggested by (Wynne, Stewart and Passmore, 2001; Allen and Moll, 1986). Genotype/phenotype related to genetic diseases were presented with an assumption that students having more attention to human health

problems. Various examples of single inheritance genetic diseases located on autosomes and gonosomes were found in genetics textbooks (Lewis, 2015) and OMIM (online Mendelian Inheritance in Man) (John Hopkins University, 2015).

Based on considered factors above, the cards were designed as follow:

1) Chromosomes on the cards were provided with locus/loci to locate genes/alleles
2) For practical use, each gene was designed to have two alleles, dominant (allele 1) and recessive (allele 2).
3) The combination of dominant and recessive alleles (heterozygote) determined the same phenotype as dominant one (allele 1)
4) Cards showed two autosomes to enable the demonstration of monohybrid and dihybrid crosses in relation to autosomal dominant/recessive inheritance pattern. The sex chromosomes enable to perform the sex-linked inheritance.
5) One autosome on the cards was designed to have two loci to extend a demonstration of linkage as well as to visualise that one chromosome contains more than a gene.
6) Stages of meiosis on the cards did not include anaphase 1 and 2, as students were assumed to be able to visualise the segregation process by putting the metaphase and telophase cards in order.
7) The cards did not show the crossing over due to the limited space to sort the cards and place all options in the students' sight on a table (by excluding the event, there were already 16 gamete possibilities to show). Furthermore, demonstration of monohybrid (one gene) or dihybrid (two genes located on different chromosomes) inheritance was not significantly influenced by the presence of crossing over.
8) Two set of cards representing meiosis in female and male parent were created to recreate the physical process of mating.

A summary of the design stages of the inheritance cards is presented on Figure 5.3.

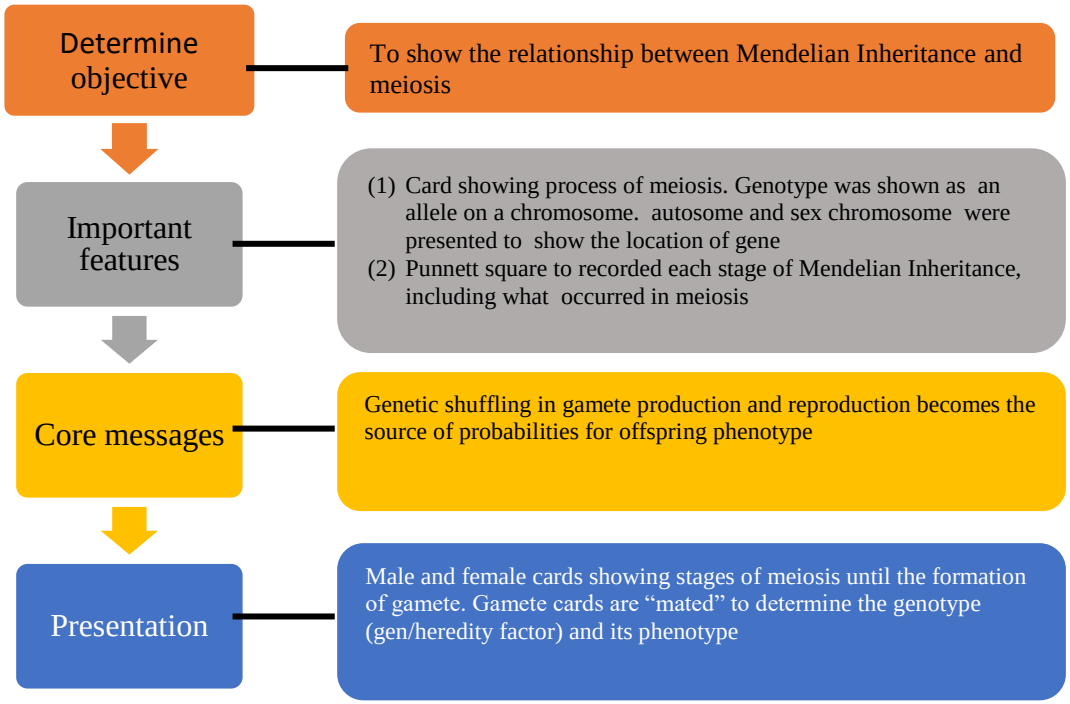


Figure 5. 3 Steps in the design of the inheritance card. *The right block details the specific events relating to each stage.*

5.3.2 The construction of the inheritance card activity

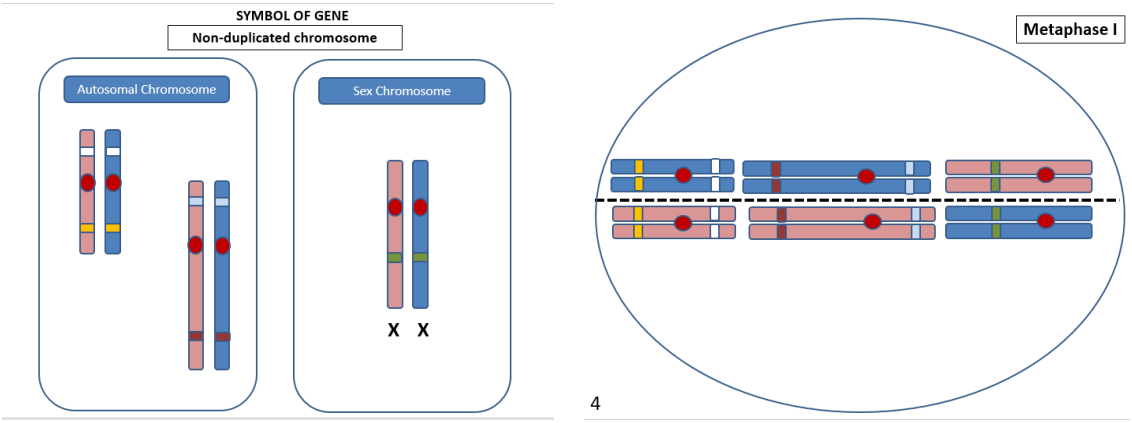
The first step in making the inheritance card activity was to create the male and female meiosis cards. All important features, for example the paternal and maternal chromosomes (homologous pair), autosome and sex-chromosome, and the loci of gene were presented on the card. Two autosomes were provided on each card to support the possibility of performing monohybrid or dihybrid cross. One (pair) of chromosomes designated to have two loci to show the concept of linkage (two or more genes located on the same chromosome and are inherited together (Klug *et al*, 2016). An example of the constructed cards is shown on Figure 5.4 (see also Appendix C-1).

The inheritance cards served as the media to incorporate the role of meiosis in the production of gamete in the crosses diagram. The relation between meiosis and Mendelian inheritance was highlighted by providing students with the crosses diagram and Punnett square table (see Figure 5.5).

The worksheet containing task activities was created to guide students in using the cards and Punnett square in observing the Mendelian inheritance. A set of information on genes responsible for specific genetic diseases/disorders appeared on the task was given on a different sheet (see Appendix C-2). The task required students to create their

own symbol of alleles for each responsible gene and to label them on the chromosomes on male and female set of cards.

Example of female cards:



Example of male cards:

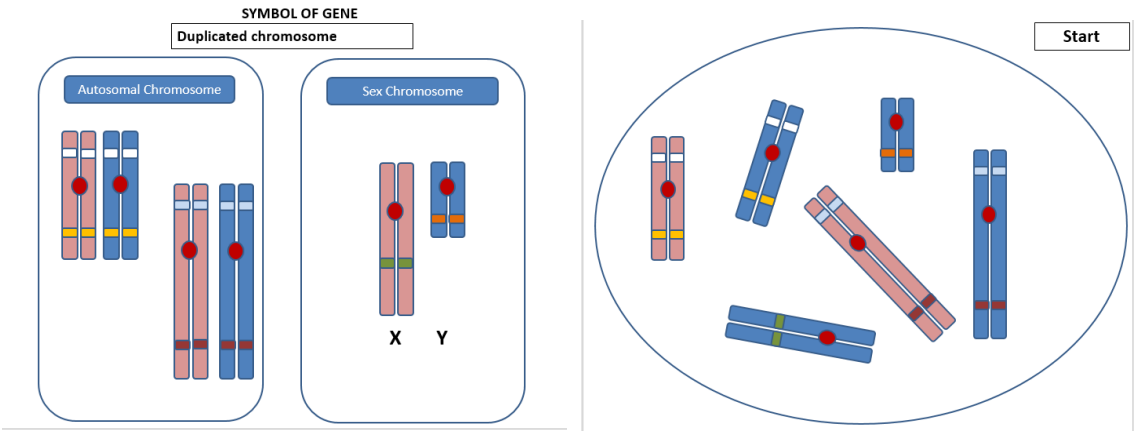


Figure 5. 4 The appearance of female and male card of inheritance card activity.
Both male and female cards showed the paternal (blue) and maternal (pink) chromosome with one or two loci. Each cell of individual male or female contains three pairs of chromosomes, 2 pairs are autosomal chromosome, and another pair is gonosome (sex) chromosome which symbolised by XX or XY. A box on the upper right of the cards contains information on the stage of meiosis. The number on the bottom left of the card (e.g. on female card) refers to one of the four possibilities of chromosome distribution during metaphase I.

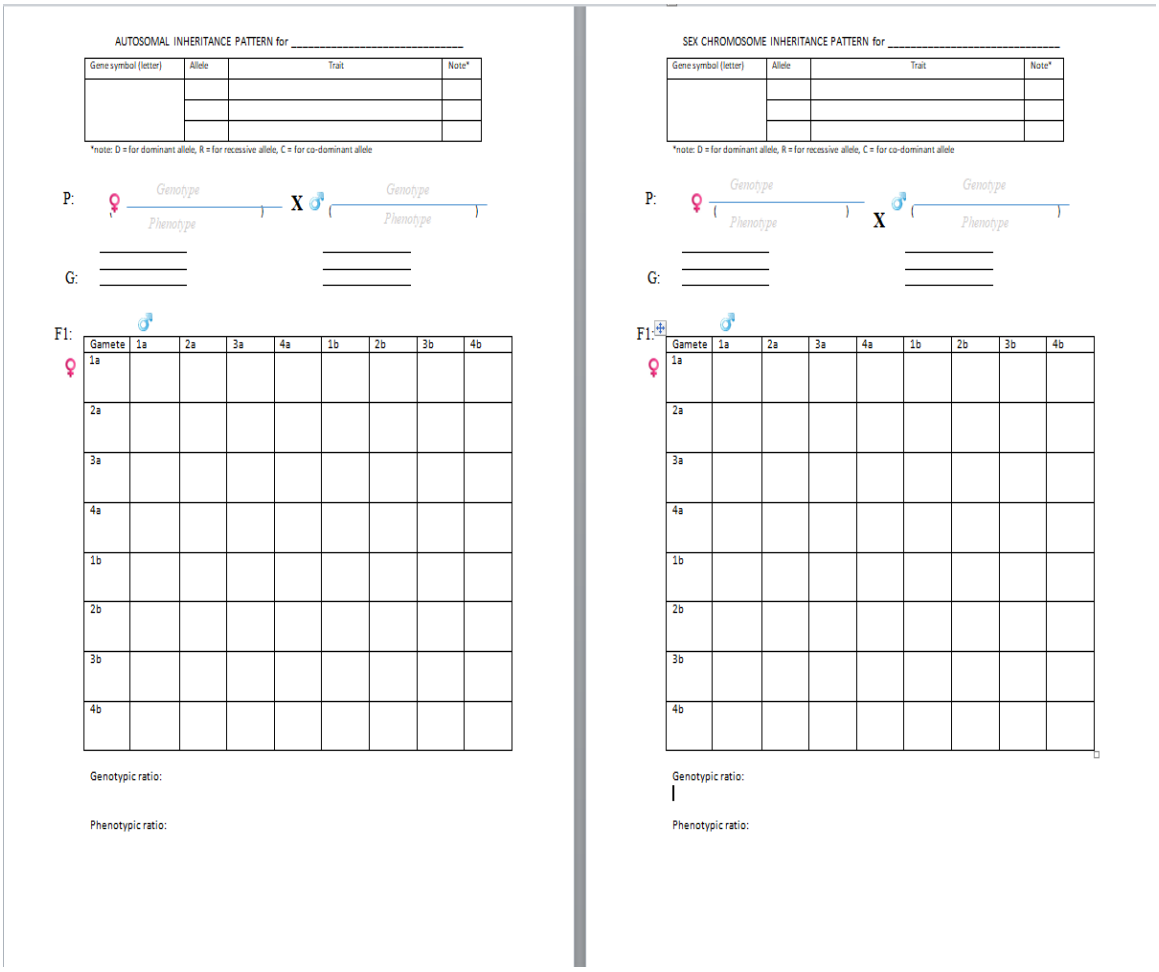


Figure 5. 5 Punnet square resources which was designed for the designated inheritance cards. *The title was differentiated to record the autosomal inheritance pattern or the sex chromosome inheritance pattern. The numbers on the Punnet square (F1, on the box) are related to the number of possible gametes on the cards.*

5.3.3 Piloting the inheritance cards activity

Piloting was a part of the development process stage. This step was conducted to observe how the resource and all the research instruments (observation and interview guidelines) worked and to anticipate the unforeseen occurrences in the future data collection (Gillham, 2005). This pilot study also informed the author's initial understanding of how students benefit from the resources and what kind of barriers in using the resource as soon as possible.

Prior to piloting with students, the card game had been shown and tried out by the original supervisors of this project, (senior members of GENIE-CETL (Genetics Education Networking for Innovation and Excellence-Centre for Teaching and Learning) at University of Leicester). They agreed that the resource would benefit

students in learning Mendelian inheritance. A concern at the time was raised about finishing the task since it required students to work with all five different traits altogether, and the small size of the card which obstructed the ability of the participants to label the alleles. Without making any changes, the same resource was piloted with a group of ten Biology education students of Universitas Tanjungpura. At the time of piloting study, the students had already covered meiosis and Mendelian inheritance in their genetics module, which gave an advantage for being able to give a critical feedback on the content and the media presentation of the inheritance cards. All students were voluntarily involved in the pilot project.

In the resource pilot study, students spent most of the allocated time to working with inheritance cards and thinking about how to label the alleles (the examples of students' work are shown on Figure 5.6). Their difficulties were not deciding on the alleles but deciding which symbol of a gene/allele they would use on their worksheet. When asked, students explained that traditionally their genetics instructor had given them the allele symbol associated with a trait in problems related to Mendelian inheritance. Therefore, although they knew that they could give any symbol to the gene of interest, they were reluctant to do so, to avoid "*making a mistake in naming the gene*" (Prita, interview/20 June 2016).

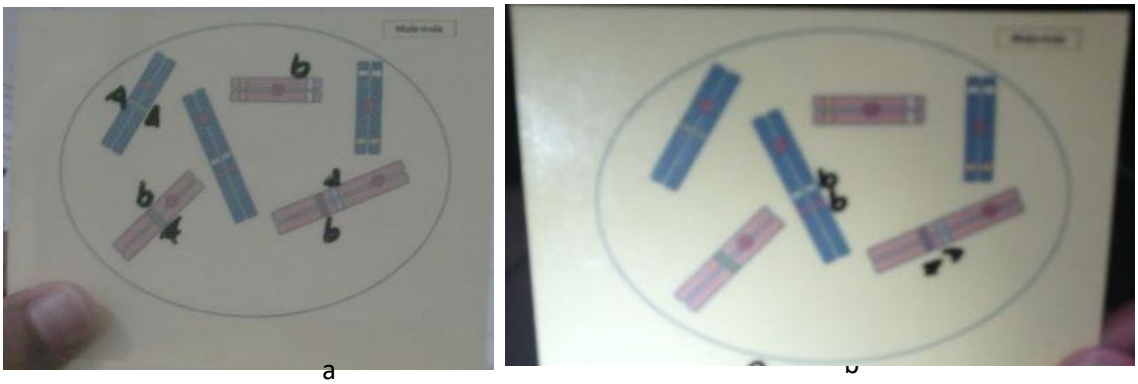


Figure 5. 6 Example of incorrect responses in writing alleles for genotype AAbb on the card game. *(a) On "beginning card", alleles b and b were put on non-homologous chromosomes. On one of chromosomes, the sister chromatids contains b and A which was impossible to perform in normal cell. (b) alleles of A,A, and, b, b were located on different locus on the same chromosomes*

After spending around 30 minutes understanding the question and deciding the symbol, they spent another 30 minutes writing the alleles on the cards. They had difficulties writing the alleles of two genes (on Figure 5.6 it was symbolised as A and

b). They wrote the alleles (AAbb) on a somatic diploid cell before meiosis. A lack of understanding of the structure of sister chromatids and homologous pair was predicted as the reason for this error. “AA” should refer to a homologous pair (paternal and maternal chromosome) containing the same alleles on the parallel locus, whilst the sister chromatids (two chromatids of a chromosome) would also be written as “AA” since they were a duplicate. Figure 5.6 showed that they did not follow this pattern in writing the alleles. When they were asked, they explained that they did this because they thought that sister chromatids contain alleles from different genes (Figure 5.6 a). According to them, this was logically correct since when chromosomes are segregated, they will be separated. Meanwhile the reason for depicting alleles (as shown in Figure 5.6 b) was due to the idea that alleles of the same gene should be located on the same chromosome. Therefore, students wrote two alleles on one chromatid on different loci. Interestingly, the four students whose concepts were depicted on Figure 5.6, were capable of define sister chromatids and homologous chromosome, but, in this context were failed to visualise the concept. This suggested that this resource was more beneficial in identifying students’ misrepresentations/misconceptions than it is in addressing them. Findings from the pilot were used to anticipate the same misconceptions in the first cycle.

The problems which were identified when piloting resource informed a revision of the instructions to the students. An additional explanation sheet dedicated to helping students with terms related to do the task was added. There was also an additional explanation to the worksheet that informing students about labelling the alleles.

5.4. Evaluation of the impact of the inheritance cards activity on students’ understanding: IND-2

The effectiveness of inheritance cards activity was first evaluated with IND-2 participants. As the pilot study was done with the students taking the same study programme and genetics module in the previous year, it was expected that the first case would identify the benefits of changes from the pilot version.

5.4.1. The existing understanding of Mendelian inheritance among Biology education students of IND-2 cohort

IND-2 students' existing understanding of Mendelian inheritance was identified through assessing their responses to the selected GCA questions with respect to the investigated concepts (Appendix C-3). Figure 5.7 showed the percentage of participants' (n=17) correct answer of the selected questions. A similar analysis also conducted to the total number of biology student teacher taking genetics module in the same academic year (n=75) in answering the same GCA questions. The depiction of latter figure served to justify the representation of participants to their respective general population in understanding concept related to Mendelian inheritance.

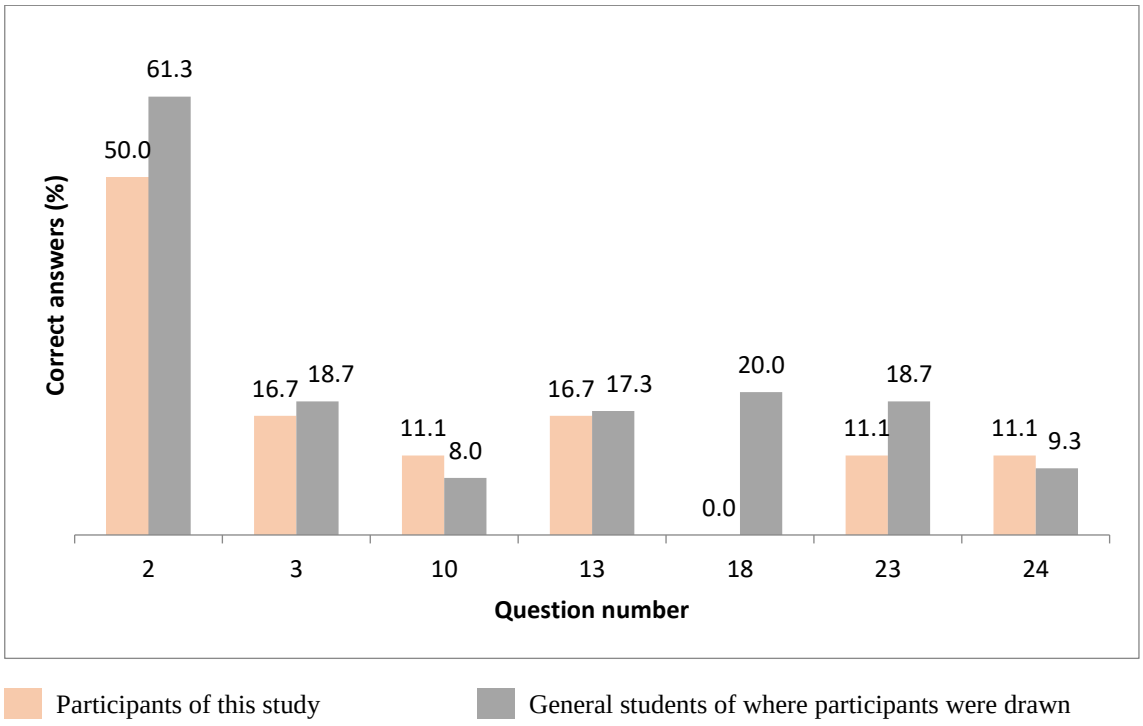


Figure 5. 7 Proportion of correct responses to GCA test given by Year 3 Biology Education students at Universitas Tanjungpura in the academic year of 2016/2017 (n=75). *GCA test was given to investigate the understanding of Mendelian Inheritance to the general population of students who was taking genetics module. They had covered Mendelian inheritance in their module prior to do the test. Colour on the diagram showed the division of the group of GCA questions.*

Based on Smith and Knight (2012), there are criteria for classifying an item of GCA questions based on the level of difficulties (see section 5.2.4, testing). Figure 5.7 suggests that all selected questions of GCA in this study were categorised as difficult questions as there were no single item where more than 80% participants are able to answer correctly. This is applied either for the IND-2 participating students in this study as well as for the general class population of the IND-2 cohort. The next stage of the

analysis involved the investigation of questions with Most Common Incorrect Answers (MCIA) for each item. Interestingly, there were more than 20% of students chose the specific single options showing the possibility of having misconoceptions (Table 5.5, column 5). The fact that the students had already covered Mendelian inheritance in their genetics module showed that their understanding of this topic was very limited. This situation was contrast to what Smith and Knight (2012) found with testing GCA to their students. They found that the most common incorrect answer (MCIA) was found in only two questions (number 3 and 10).

The difficulties in answering question number 2 rests on the lower understanding of how to differentiate the genotype of daughter cells of meiosis with those of mitosis (24% of IND-2). The same difficulty was also revealed when analysing responses from the same group (IND-2) to MCI test question number 17 (see Table 4. 11). A similar pattern of difficulties was also found in answers to question number 13 of GCA with question number 6 of MCI. Students' responses on these two corresponded questions showed that they tended to have one of two incorrect ideas, of either (1) locating all dominant and all recessive alleles to separate chromosome (31% GCA, 28% MCI), or (2) locating dominant and recessive alleles on different loci of the same chromosome (35% GCA, 35% MCI). The similarities pattern of incorrect ideas between the two questions of GCA with the corresponding questions of MCI indicated that students have a misconception related to meiosis that still persist even after students watch the educational video of meiosis.

The rests of the GCA questions were related to the principle of Mendelian Inheritance. From analysing students' responses, it is revealed that students misunderstood the principle of determining patterns of inheritance and in gene shuffling. Students' response of GCA number 3 showed their confusion in determining what qualifies as to decide as X-linked inheritance. About 77% of student's population (including 71% of IND-2 participants) indicated that a genetic disease may follow the X-linked inheritance for it is consistently found only on woman. However, the correct idea should be the opposite (if it is consistently found on man) as woman acts as a carrier (Cummings, 2006). Students' responses to number 24 also showed they are confusing the effect of crossing over with random assortment on gene shuffling. Both events occurred on meiosis, but the latter was involved in shuffling the parental chromosomes on producing gamete, instead of performing alleles swapping (Klug *et al*, 2016).

Table 5. 5 The possible difficulties explained from the common incorrect answer of pre-test GCA chosen by Biology Education students at Universitas Tanjungpura in the academic year of 2016/2017

GCA was given to Biology education students near their completion of their Genetics module. Students received no learning intervention with inheritance cards prior to the test. Column (1) refers to the number of the question in the GCA. Column (2) shows the theme of each question number. Column (3) shows the category of questions based on students answer as reviewed by Smith & Knight (2012). Column (4) shows the percentage of general population students choosing specific incorrect options categorised as MCIA. Column (5) shows the percentage of IND-2 cohort choosing specific incorrect options categorised as MCIA. Column (6) gives the interpretation to the possible difficulties (misunderstandings) derived from the largest proportion (>20%) of students choosing certain options.

No	Topic of questions	Category of difficulties*	Percentage (%) of students choosing most common incorrect answer (MCIA)**		Possible difficulties from common incorrect options
			General Population (n=76)	IND-2 cohort (n=17)	
(1)	(2)	(3)	(4)	(5)	(6)
2	Predicting alleles' distribution of a gamete from a cell (FfQq) which undergoes normal meiosis	II/III	-	24	Considering each gamete contains one of four (4) chromosomes/alleles (F,f,Q,q)
3	Predicting location of gene on the chromosome if the related phenotype (inherited disease) only affect women	III	77	71	The gene is on the sex chromosome, indicating a confusion to the principle of criss-cross inheritance
10	Predicting possibility of second child who does not have cystic fibrosis having heterozygous allele for cystic fibrosis (both parents are heterozygous for cystic fibrosis, the first child has cystic fibrosis)	III	45 28	29 41	When two heterozygotes mate, probability calculations do not need to be adjusted even if an offspring is known to be unaffected It is highly likely including calculating possibilities of heterozygotes for all children (first and second one)
13	Predicting possible representation of two heterozygous genes located on the same chromosomes (linked)	III	31 33	35 35	All dominant alleles on one chromosome, all recessive alleles on its chromosome pair Two alleles are located on one chromosome
18	Calculating probability of a son having haemophilia if genotype grandmother is known as heterozygous	III	36 24	47 24	Considering that genotype of mother only homozygous dominant Calculating possibilities for all possible children, calculations do not need to adjust even when the gender of a child had been known
23	Predicting the effect of replication to the	III	31	41	Before meiosis, sister chromatids have different alleles,

	representation of chromosome		32	32	replication doubles the chromosome number Sister chromatids have different alleles
24	Predicting possibility for offspring having genotype of Re (linked) from parents having genotype of RE (linked) and re (linked)	III	45	47	It is the random assortment process that mix alleles on meiosis

Notes:

* Categories of difficulties:
I = not difficult, *if the percentage of incorrect answer > 80%*
II = difficult but no common incorrect answer, *if the percentage of incorrect answer > 80% but no single specified option chosen by more than 20% participants*
III = difficult, with a common incorrect answer, *if the percentage of incorrect answer > 80% and there is/are specified option(s) chosen by more than 20% participants*
** MCIA was recognised from a difficult question with (a) specified incorrect option(s) chosen by more than 20% of participants
(Based on criteria which cited from Smith & Knight, 2012)

Furthermore, the same cohort also showed low level of understanding of how to calculate probabilities (number 10 and 18). Performing calculation in a crosses required not only an ability in mathematics but also common sense in determining the genotype (Lewis, 2015). For example, students should be able to derive a conclusion that a woman with a curly hair whose mother has a straight hair and father used to have curly hair before going bald as having heterozygote genotype (with an assumption that curly hair is dominant to straight hair). The common-sense ability is also needed to adjust the probability of calculation when a certain situation was known (Smith and Knight, 2012).

The analysis of the GCA questions suggested that this group of general population students did not only have a difficulty visualising concepts related to inheritance (including meiosis) as suggested by many papers (e.g. (Wynne, Stewart and Passmore, 2001; Knipples, 2002), but to include problems in calculating probabilities and identifying patterns of inheritance.

5.4.2 Impact of the Inheritance cards: IND-2

The effectiveness of the Cards of inheritance activity in promoting students' understanding of the connection between meiosis and inheritance was indicated by (1) the improvement of understanding relating to the concepts connecting meiosis and inheritance, and (2) students' engagement in revising the concept. The effectiveness of the resource to support students in understanding the links between meiosis with Mendelian Inheritance was assessed through the changes between pre and post-test of GCA, and through analysing any changes of previously incorrect concepts through interview. The latter function was assessed through analysing participants' perception of the resource in the interviews which was confirmed with the actual observation of their engagement with the resource.

Figure 5.8 shows the comparison between participants' pre-test and post-test of GCA. An improvement of understanding indicated by the increasing percentage of IND-2 students giving a correct answer was detected for question numbers 2, 13, 18 and 23. However, the figure also shows a decrease in the proportion of correct answers for number 3, 10 and 24.

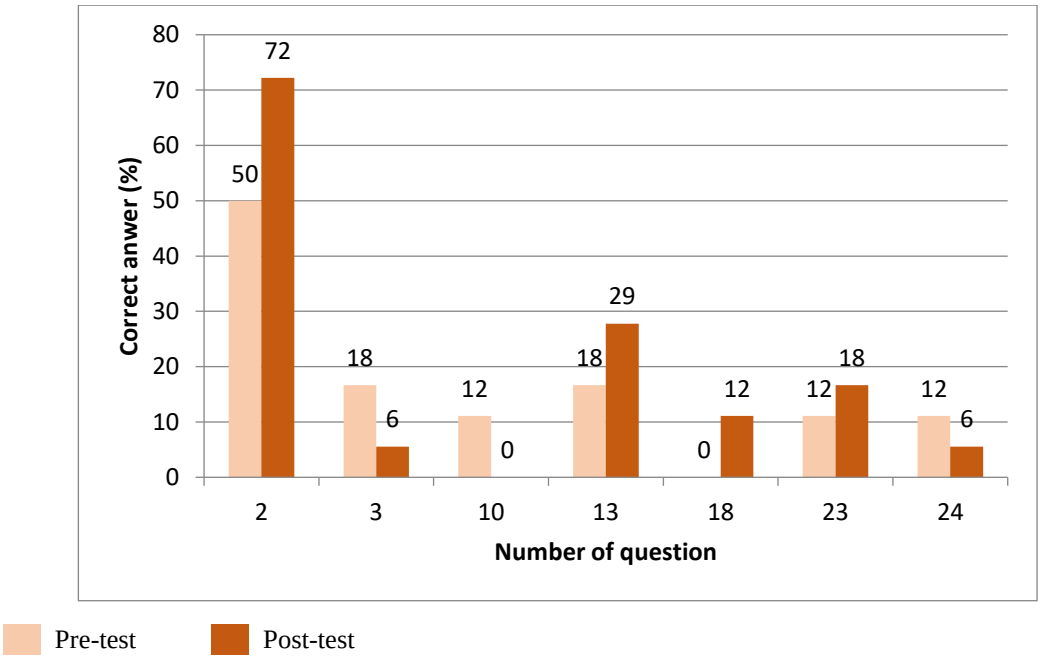


Figure 5. 8 A comparison between correct answer for selected questions of GCA test before (pre) and after (post) working with the inheritance cards for IND-2 (n=17). *This figure shows a comparison based on the groups of questions. GCA pre-test was given two weeks before trying out resources, while post-test was given after the learning session. An improvement in giving correct answer was observed for number 2, 13, 18 and 23, while there was a decrease for questions number 3, 10, and 24.*

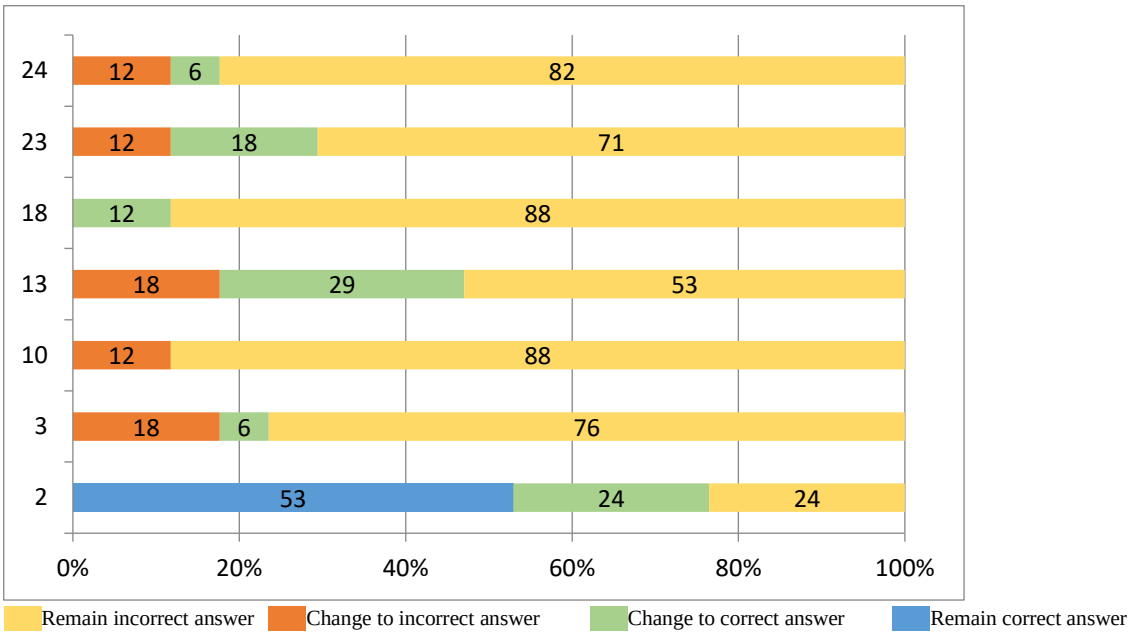


Figure 5. 9 A comparison between type of changes on the answer of GCA test before (pre) and after (post) trying out the inheritance cards for IND-2 group of participants (n=17). *The types of changes in the answers are presented per selected questions of GCA.(Notes: The percentage shown here was rounded up/down to the closest number, which may not result in 100% in each al if more than one was rounded up).*

A further investigation of the individual students' changes of answer from pre to post-test shows an interesting finding: question number 2 is the only questions for which students who answer correctly in pre-test maintain their correct answer in post-test (indicated by the blue line on Figure 5.9). For most of the other questions, there was a trade-off between the percentages of students who answer correctly on pre-test with those who answer correctly on post-test. Some IND-2 participants who answered correctly on pre-test changed their response to the incorrect one on the post-test, while other students who gave incorrect response on pre-test changed their response to the correct one on post-test (see number 3, 13, 23, and 24 on Figure 5.9). Thus, although Figure 5.8 suggests that there was an improvement in students' understanding on several questions (number 2, 13, 18 and 23) this was true only for number 2 and 18. Similarly, the decreasing proportion of correct responses on number 3 and 24 was caused by all students who previously answered correctly were changing their answer to the incorrect one.

In an attempt to search for the misconceptions which are responsible for of students' repeated choice of the incorrect answer, a further analysis was carried out based on the work of Smith & Knight (2012) and is presented on Table 5.6. It shows that the ratio of students categorised as having misconceptions (as determined by the MCIA option they have chosen) for each question was varied. Question number 2 was categorised as a difficult question, however, no MCIA was detected. The fact that there is no MCIA in the post test and the increase in students answering this question correctly (see above paragraph) suggests the potential function of inheritance cards in assisting students in understanding the distribution of alleles' in gamete production. In addition, the high percentage of students choosing MCIA for other questions might indicate that the inheritance cards activity did not effectively help students to understand concepts associated with the relationship between meiosis and Mendelian inheritance. This was particularly true for question number 3 where 59% of participants conducted the same mistake by choosing MCIA option both in the pre and post-test. This might have happened because the inheritance cards activity did not fully provide students with an opportunity to observe events related to sex-linked pattern of inheritance. An observation of students' misconceptions in other numbers showed it happened for a relatively lower ratio than for question number 3.

Table 5. 6 The possible misconceptions explained from the most common incorrect answer (MCIA) of post-test GCA chosen by IND-2 cohort (n=17)

Post-test GCA was given directly after the learning intervention with inheritance cards prior was conducted. Column (1) shows the selected number of GCA question use in this study. Column (2) shows the respective topic of question. Column (3) shows the total percentage of incorrect answer for each question. Column (4) shows the percentage of incorrect answer categorised as MCIA. Column (5) refers to the percentage of students categorised as having misconceptions. Column (6) points out the possible explanation of misconceptions derived from the MCIA.

Question number **(1)**	**Topic of question** **(2)**	**Categories of question*** **(3)**	**Percentage (%) of students choosing MCIA**** **(4)**	**Percentage (%) of students having a misconception***** **(5)**	**Possible misconceptions explained from MCIA** **(6)**
2	Predicting alleles' distribution of a gamete from a cell (FfQq) which undergoes normal meiosis	II	-	-	-
3	Predicting location of gene on the chromosome if the related phenotype (inherited disease) only affect women	94 (III)	76	59%	The gene is on the sex chromosome, indicating a confusion to the principle of criss-cross inheritance
10	Predicting possibility of second child who does not have cystic fibrosis having heterozygous allele for cystic fibrosis (both parents are heterozygous for cystic fibrosis, the first child has cystic fibrosis)	100 (III)	35	18%	It is highly likely including calculating possibilities of heterozygotes for all children (first and second one)
			47	18%	When two heterozygotes mate, probability calculations do not need to be adjusted even if an offspring is known to be unaffected
13	Predicting possible representation of two heterozygous genes located on the same chromosomes (linked)	72 (III)	53	12%	One chromosome must contain dominant allele of a gene, and recessive allele for another gene
18	Calculating probability of a son having haemophilia if genotype grandmother is known as heterozygous	89 (III)	53	24%	Considering that genotype of mother only homozygous dominant

23	Predicting the effect of replication to the representation of chromosome	83 (III)	41	12%	Before meiosis, sister chromatids have different alleles, replication doubles the chromosome number
			24	12%	Sister chromatids has different alleles
24	Predicting possibility for offspring having genotype of Re (linked) from parents having genotype of RE (linked) and re (linked)	94 (III)	65	24%	It is an event of random assortment that perform allele swapping on meiosis process

Notes:

* Categories of difficulties:
I = not difficult, *if the percentage of incorrect answer > 80%*
II = difficult but no common incorrect answer, *if the percentage of incorrect answer > 80% but no single specified option chosen by more than 20% participants*
III = difficult, with a common incorrect answer, *if the percentage of incorrect answer > 80% and there is/are specified option(s) chosen by more than 20% participants*
** MCIA was recognised from a difficult question with (a) specified incorrect option(s) chosen by more than 20% of participants
*** Students were categorised as "*having a misconception*" when they chose the same incorrect MCIA in pre and post-test. The percentage presented on column 5 were related to column 4 in a way that they derived from total number of participants. Thus, it was read as: for example number 3, 76% participants chose MCIA, 59% participants chose MCIA repeatedly.

(Based on criteria which cited from Smith & Knight, 2012)

The inheritance cards were expected to help students to visualise meiosis and its subordinate concepts, for example alleles' distribution during different stages of meiosis, as well as relating the concept of meiosis with Mendelian inheritance crosses. The cards were not designed to directly support the integration of additional information to calculate the probabilities to solve question number 10 and 18, though there was a dedicated section which asked students to do simple calculation. This fact together with the large number of "trade-offs" for correct answer, makes it difficult to say that students have a general improvement in the concepts assessed. Thus, more information on how the inheritance cards activity did assist students in learning concepts related to the relation between meiosis and Mendelian inheritance was obtained through analysing IND-2 responses in interviews. Table 5.7 showed the individual understanding of concept of Mendelian inheritance, and the visualisation of the location of the gene/alleles leading to the understanding of the different patterns of autosomal or sex-linked inheritance pattern.

Students were expected to recognise several features of Mendelian inheritance in responding to the definition of Mendelian inheritance, such as: a single factor (gene) controls an expression of a single trait (phenotype); the mechanism of transmission involving two alleles (dominant and recessive); the two alleles could either be homozygote (two dominant or two recessive alleles) or heterozygote (one dominant-one recessive allele); and in the case of heterozygote offspring, the dominant allele determining trait will be expressed. Information on characteristics was given to the students as a source of information when they worked with the cards.

Unexpectedly, IND-2 students' responses did not confirm the expectation. First, not all participants understand what qualifies as Mendelian inheritance (Table 5.7). Sammy (pseudonym) could not mention any characteristic of Mendelian inheritance, while three other students defined Mendelian inheritance in different way. Both Mimi and Raras identified Mendelian inheritance through the presence of any crosses (mating) between two individuals, and Unika defined Mendelian inheritance as any crosses matching the expected probability calculation 9:3:3:1 for dihybrid crosses. The latter definition of Mendelian inheritance is interesting, since adoption of certain template for any calculation indicated the lack ability to adjust calculation based on the context of the question. Figure 5.10 showed Mendel's dihybrid crosses typically showed in the textbook of biology (e.g. Campbell, 2014) and genetics (e.g. Cummings, 2006).

Campbell (2014) biology textbook served as standard book of genetics module for IND-2 cohort. Having an idea to link all problems related to calculating probability in Mendelian inheritance with Mendelian cross monohybrid and dihybrid ratio was thought as a factor that hindered students from adjusting calculations in different situation/context, which may explain why the majority of students taking genetics module in this academic year could not give correct answer to GCA question number 10, which asked about a similar principle (see Table 5.3).

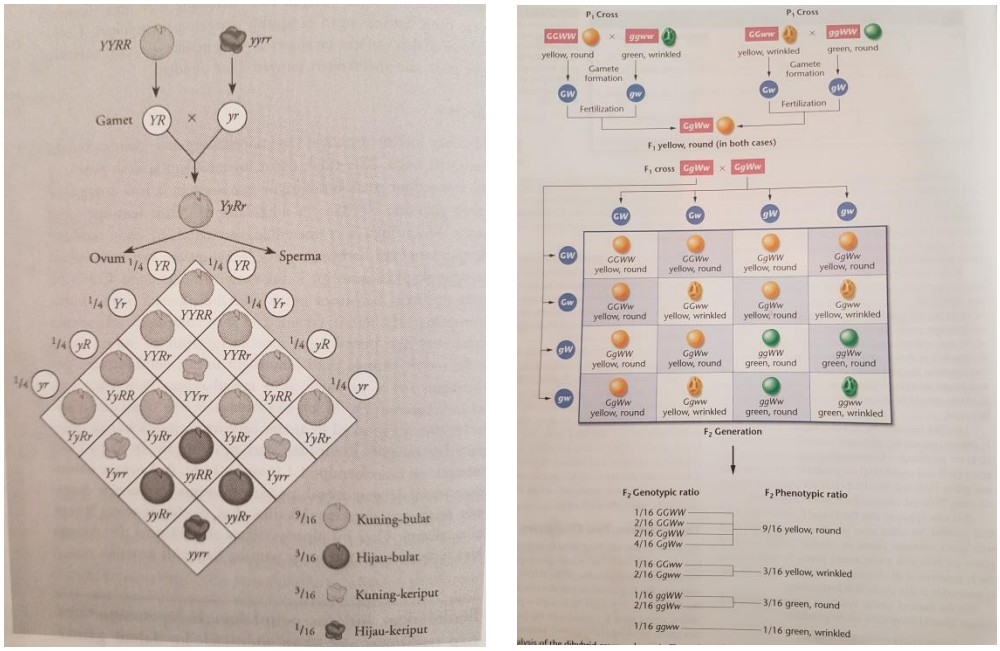


Figure 5. 10 A diagram of dihybrid Mendel' crosses showing the phenotype ratio of 9:3:3:1. *As depicted on left: Biology textbook written by Campbell (2014) and right: Genetics textbook written by Klug,et al., (2016)*

Table 5. 7 IND-2 participants understanding of concepts related to principle of Mendelian inheritance and location of respective heredity factor (gene) on the chromosome (n=17)

The crosses diagram which was used as the elicitation for discussion of Mendelian inheritance principle was presented on the first row. Based on the diagram, students were asked questions related to their concept of Mendelian inheritance and the location of the gene (based on what they have conducted with inheritance cards). The description of students responses were presented on the three columns following the pseudonym.

P: ♂ $\frac{AB}{ab}$ (Normal, Brachydactylic) x ♀ $\frac{ab}{ab}$ (Albino, Normal)

G: AB, Ab, aB, ab ab

F1:

♀ \ ♂	AB	Ab	aB	Ab
Ab	$\frac{AB}{ab}$ (Normal, Brachydactylic	$\frac{Ab}{ab}$ (Normal, Normal)	$\frac{aB}{ab}$ (Albino, Brachydactylic)	$\frac{ab}{ab}$ (Albino, Normal)

Pseudonym	An indicator of the occurrence of Mendelian (single gene) inheritance	Mendelian Inheritance pattern showed on the crosses diagram	Location of gene (Autosomal/Sex chromosome)
Aliya	There are dominant and recessive alleles	**YES**, the crossing involved disease-related trait (not involved trait such as pea/walnut which was taught as an example of modification/extension of Mendel) and they have dominant (AB) and recessive (ab) alleles	**Autosomal chromosome**
Azmi	Each gene (A or B) determines a trait	**NO**, the two genes (Brachidactily and Albino) were observed together	Sex chromosome
Bona	One gene codes for only one trait (the same gene do not code for other traits)	**YES**, Albino and Brachidactily are determined by two alleles, the dominant and recessive alleles	Cannot decide, should be informed
Dina	A trait is coded in the DNA of a chromosome	**YES**, there were two independent traits	Autosomal chromosome; Brachidactily follows the autosomal dominant inheritance pattern
Faiza	An expression of one gene did not affect an expression of other genes	**YES** expression of gene A did not affect expression of gene B; the pattern of inheritance for gene for Albino (recessive) is different from the gene for Brachidactily (dominant)	Cannot decide, should be informed

Gandhes	Offspring share the same phenotypes (trait) as of its parents	**YES**, the diagram shows the transmission of trait	Sex chromosome, there are male and female (individual) on the diagram
Hana	One gene codes for one trait, there are monohybrid and dihybrid	**YES**, there were two independent traits (dihybrid)	Cannot decide, should be informed (though she remember that albino is on autosome)
Ika	*(do not give direct explanation)*	**YES**, there are two independent traits (albino and brachidactily)	*(do not mention on what chromosome)*
Karina	Offspring share the same phenotypes (trait) as of its parents	**YES**, there is a crosses involving three phenotypic traits (normal, brachidactily, albino) which the traits also shown on the offspring	Autosomal chromosome; the dominant trait (possibly refers to prominent trait) follows the autosomal recessive inheritance pattern
Mimi	There is mating (crossing) to produce gametes	**YES**, there are 4 gametes with a pattern of 3 dominant: 1 recessive	Autosomal chromosome; because there are 4 gametes, sex chromosome only produces two gametes (possibilities) X and Y
Omar	One gen codes for one trait only (only deal with an inheritance of one trait)	**NO**, alleles do not represent one gene	Autosomal chromosome; not linked to the sex because the phenotypic trait could be observed
Raras	A crossing involving several traits (as demonstrated by Mendel with peas)	**YES**, it shows crossing (mating) which involves several traits	Sex chromosome, phenotype of offspring as a testing to determine that the parents are normal (suggesting a link with test-cross/ back-cross)
Sammy	*(not remember)*	*(did not know)*	*(did not know)*
Unika	A Mendelian pattern is 9:3:3:1	**YES**, it shows crossing (mating) involving several traits (as demonstrated by the questions related to Mendelian inheritance at high school/college)	Cannot be considered, should be given in the instruction
Vani	There is a single trait which is inherited by an offspring	**YES**, the offspring has the same traits as of parents (no modification to Mendelian inheritance)	sex chromosome, particularly X, because more gametes are produced by X (possibly refers to female reproductive cell)
Vira	One trait is coded by one gene	**YES**, each trait is determined by a gene; A and B are located on the different chromosomes	*(do not mention on what chromosome)*
Yeyen	Crossing between parents to produce two daughter cells)	**YES,** the crossing involved two parents and produce *two daughter cells* as Mendel showed in a dihybrid crosses of peas	*(do not mention on what chromosome)*

Students with an understanding of the principles of Mendelian inheritance did not automatically able to apply them in recognising the characteristic of Mendelian inheritance in crosses diagram. Only eight out of 17 students (Aliya, Bona, Faiza, Hana, Vani, and Vira, Dina and Ika) identified Mendelian inheritance are applied in the inheritance mechanism of two independent traits and gave a correct reason. The majority of students could not explain why the inheritance of two independent genes shown on the diagram qualifies as Mendelian inheritance. Azmi and Omar were two students who considered that the two traits were not followed the Mendelian inheritance pattern. Azmi's statement suggested that he misunderstood the term "single gene" of single gene (Mendelian) inheritance as only one gene observed at one time (as demonstrated on monohybrid cross). Meanwhile, Omar misconceived the symbol of two genes (e.g. ab) as abnormal written symbol for an allele of a gene.

In responding to the question related to patterns of inheritance, students had difficulty in determining whether genes for the two related traits (Brachidactily and Albinism) are located on the autosome or sex chromosome. From five out of 17 students (29%) who had identified that two genes are on the autosomes, only Dina correctly identified the difference of inheritance patterns between those two traits, the autosomal dominant patterns of Brachidactily and the autosomal recessive pattern of Albinism. The other four students did not relate their answers to the patterns of inheritance. The rest of the students came with incorrect understanding of the location of the gene, as they assumed the genes were located on the sex chromosome (24%), located on both autosome and sex chromosome (24%), and did not have idea about the gene's location (24%).

5.4.3 IND-2 Students' perception of the inheritance cards activity

Students' perceptions of their learning experiences using the inheritance cards were important (Gagné *et al*., 2005; Gall, Borg, and Gall, 2003). An investigation of students' perceptions may also inform the possible conceptual changes students may experience in addition to the information gained from analysing the test and the interview. A summary of students' perceptions toward the inheritance cards is presented on Table 5.8.

Table 5. 8 A summary of IND-2 students' perception toward the inheritance cards from the interview after trying out the resource (n=17).

Students' evaluation to the inheritance cards activity was described based on the points of evaluation (descriptor). A number in the bracket following a description [ ] refers to the number of students stating the description. Categorisation is not mutually exclusive, one individual may contribute to more than one categories.

Descriptor	Description
Benefit	1. Visualisation of relations between Meiosis-Mendelian inheritance [3] 2. Recognising patterns of inheritance: - Y-linked patterns [1] - Autosomal inheritance [1] 3. Understanding concept of meiosis: - Gamete production [2] - Events [3] 4. Modelling Mendelian crosses [1] 5. Chromosome structure: - Homologous chromosomes [3] - Alleles [3] 6. Understanding the rules [2]
Problems	1. Did not have solid foundation on understanding subordinate concepts: - homologous chromosome [3] - symbol of alleles [2] 2. Difficulty in understanding the task instruction [6] 3. Difficulty in understanding analogy on the cards (e.g. why there are reversible cards, the function of coins, different colours of loci and parental chromosome) [2] 4. Did not fully participate [1]
Favourite parts	1. To labelling alleles [5] 2. To sorting cards in order [2] 3. To observe chromosome behaviour on sorted cards [1] 4. Feeling challenging in determining loci and labelling alleles [3] 5. An opportunity to observe patterns of inheritance (Y-Linked) [1]
Least favourite parts	1. Confused with the instruction in the beginning [1] 2. To label alleles on all cards, for this a time-consuming activity [2] 3. Answering the questions on the worksheet, because need to think [2] 4. Performing crosses, because did not know the rules [1]
Suggestion	1. No need to change [3], though need to clearly instruct students to follow all provided guidance [1] 2. Clear instruction on how to sorting the cards [1] 3. Giving verbal instruction in the beginning [1] 4. Provide the result cards (gamete) as a check point [(1] 5. Clear instruction on how to label alleles [2] 6. Providing more steps and challenging question [1] 7. Providing clear explanation of the symbol on the cards (e.g. the meaning of 1a, 2a) [1]

Despite the problems experienced by students during their learning session using Inheritance cards, students thought that doing the activity improved their understanding of concepts related to meiosis and its subordinate concepts (e.g. structure of

chromosomes), crosses, or both (see Table 5.8). Eleven out of 19 comments (58%) on the benefits of the resource pointed to its value in helping them achieve a better understanding of meiosis (including its subordinate concept of a chromosome structure). When interviewed, most participants related this advantage with the opportunity to observe the sequence of meiosis on the cards. During the interview, Omar mentioned the role of inheritance cards in helping him to understand the random assortment process better. His statement is confirmed by the observation notes that state while Omar working on his group, he sorted the cards and observed the metaphase I. He explained the concept of random assortment correctly. He later said that he just found out how random assortment acts by sorting the cards and observing the four metaphase 1 cards on the table, something that he did not understand when he previously watched the video illustrating meiosis (Observation notes/15 December 2016). Aliya and Hana revealed the role of the cards in helping her understand meiosis, particularly in the process of gamete formation. She obtained this new understanding by sorting the cards and observing the chromosome distribution in different stages of meiosis while random choosing variant of gametes (Observation notes/15 December 2016).

Conducting the activity of sorting and observing the cards also benefitted students in revising their concept of homologous pairs and loci of genes (alleles), the subordinate concepts of meiosis. Raras was one of the students who get the benefit. In the interview, she pointed out that she had difficulty on labelling alleles in the beginning and realised that understanding concept of homologous chromosomes to enable correctly labelling alleles are important. She was able to revise her understanding of homologous chromosomes and alleles through conducting the activity.

> *"...* [to labelling alleles] *is the first time I do it* [in this activity]. *... I understand better ... for example, sister chromatids, they have similar locus,* [we labelled] *half here and there... if, for example anaemia* [are symbolised by] *alleles Ff, we labelled F here* [point out one locus of chromosome], *and not there, that is for another gene"* (Raras/interview2/20 December 2016)

The process of labelling alleles also mentioned by five out of 11 students (45%) as the activity they most enjoy. The benefit of labelling alleles while revising the structure of allelic distribution and homologous chromosomes (to differentiate the pair from sister chromatids) were the reasons for improvement on score GCA number 2 and 13.

Other reported benefits were related to learning Mendelian inheritance. Two out of 19 comments (11%) mentioned the activity helped them to recognise patterns of

inheritance. The two students (Faiza and Hana) highlighted different steps in the Inheritance Activity that helped them in recognising the pattern. Faiza claimed the understanding came as she observed the Y-linked patterns of inheritance from labelling the chromosomes on the cards. Meanwhile, Hana understood the pattern when she observed the autosomal patterns of inheritance while sorting and labelling the cards.

Among comments of the benefit of the resource, three students-(16%) mentioned the benefit of this cards resource in visualising the meiosis-Mendelian inheritance relationship. Amongst the three, Bona's comment was the most interesting. Apart from just seeing the link between meiosis and Mendelian inheritance, she also included the additional benefits of observing a sex-linked gene and a concept of linkage, and of predicting the phenotype of offspring. However, despite the benefit, she described a limitation of the cards which (i.e. the instruction of labelling alleles).

> *"I have difficulty in determining gamete on each card. Em… how they* [alleles] *are located. … We wrote symbols [of alleles] of several genetic diseases … well, when I visualised them on cards, it is difficult, because of the instruction on the two cards* [male and female cards]. *… We just wrote them [symbol of alleles] as we want on the cards… When we read the instruction on the cards, it is said that alleles* [on a chromosome] *have to be paired up with homologous pair…"* (Bona/interview2/18 December 2016).

Interestingly, her articulation of the problems she faced in doing activity with the inheritance cards not only revealed the problem in reading the instructions, but the pre-existing understanding of pairs of alleles. She misconceived the pairs of alleles have no relation with the pairs of homologous chromosomes. The Inheritance cards activity in revealing this misconception shows the potential impact of using of this activity to better understanding student learning of these concepts. Hence, it might be used to revise students' visualisation allelic concepts accordingly.

From analysing students' favourite and least favourite parts (see Table 5.8), the data shows that students' comments were mostly related to the benefit or problems in doing the cards activity. The most enjoyable activities of labelling alleles (45%) and sorting the cards (18%) were associated with the learning of mechanism of meiosis and revising their understanding of the structure of chromosomes. Students' comments of other favourite parts were also related to the feeling of achievement of understanding any related concept while doing the resources, this was more important to the students than simple enjoyment of the activity without achieving any learning. In addition to this, students disliked the parts of the resources that confused them and prevented them from

understanding how the cards inheritance activity works. For example, Dina said in her interview (Dina/interview2/17 December 2016) that she did not like the fact that labelling alleles was time consuming activity that gave her have less time to observe and complete the questions. This suggested that the understanding of concepts which were supported by undertaking the activities were a factor that leads to students liking or disliking them.

The benefit of using resources is not only revealed through students' interviews, but through observation. This was well demonstrated through analysing Dina's group work. Dina worked in a group with Azmi, and Nonik. They started with writing incorrect alleles in the beginning (see Figure 5.11). They wrote all sex-linked genotypes, X-linked (XBXb) and Y-linked (XHXH) genes, on female reproductive cell cards which supposedly consisted of only X-linked genotype (no Y-chromosome). To fit in their idea, they wrote the symbol for hypertrichosis (which was supposed to Y-linked) XHXH in the same location with colour blind allele (XBXb), which was incorrect as each gene is located in a specific locus. In doing this, these students also showed their erroneous understanding that–every gene should be on both male and female reproductive cells, despite the genes being sex-linked. They kept their idea until they had to write alleles for both genes at telophase 1, where there is only one locus on X-chromosome while they have to write alleles of Xb and y altogether. This step made them stop and reflect back on the initial stage of writing alleles where they realised the difference between the X and the Y chromosome, and that hypertrichosis only appears on the Y-chromosome. They students then changed their crosses diagram to apply their revised understanding accordingly (Observation notes/14 December 2016). The process described above suggested that the cards could benefit students to revise their conceptions by visualising the concept of autosome and sex chromosome (X and Y) and showing the process of segregation and getting the probability of gametes. Figure 5.11 shows the steps of the activity and how this can help improve students' understanding of sex chromosome and autosome.

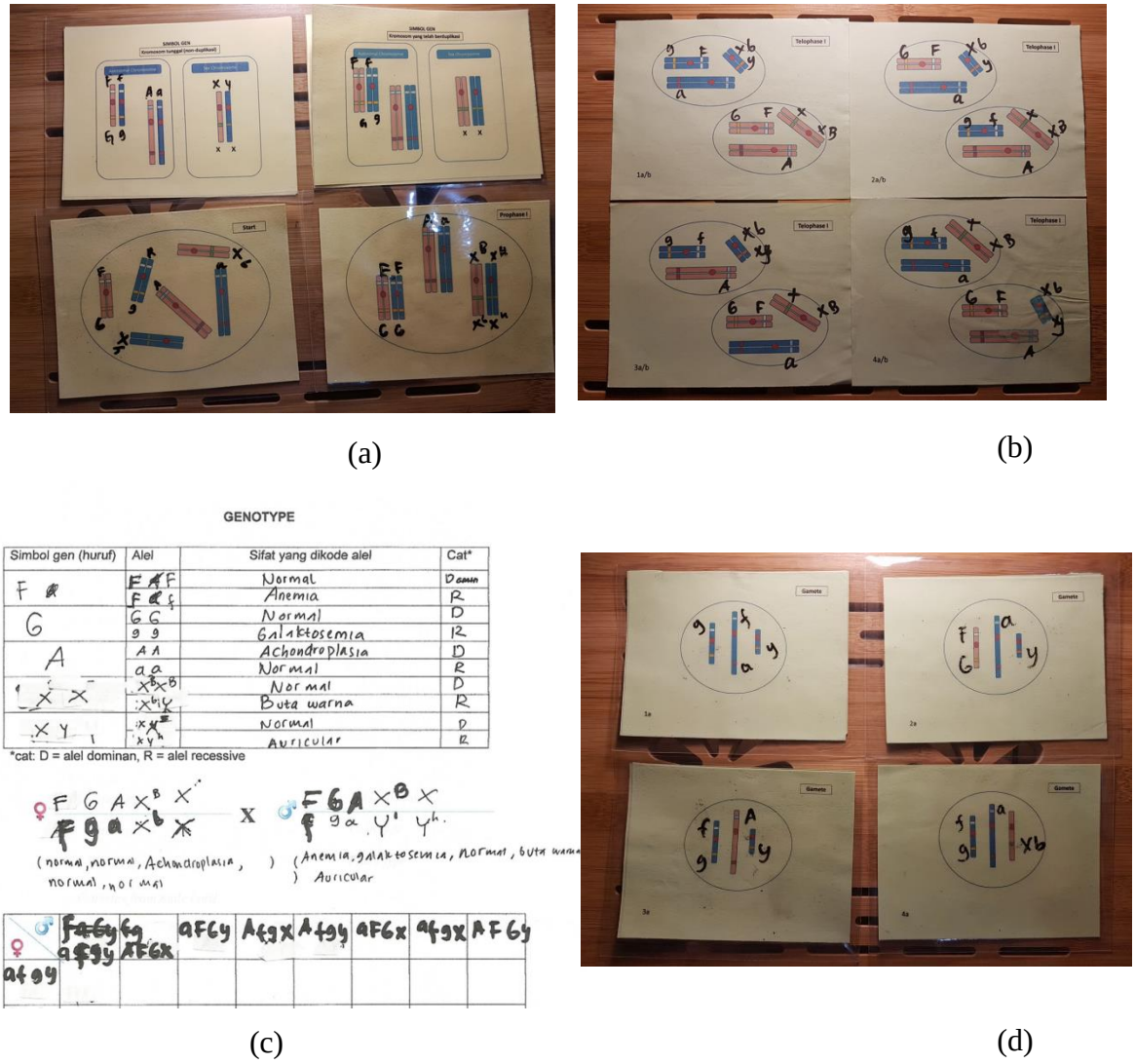


Figure 5. 11 An Inheritance cards activity recording from one of the IND-2 groups showing progress understanding to the concept of sex chromosome by conducting the activity. *The picture showed the progress understanding of sex chromosome from: (a) started with incorrect idea of both X-linked (X^BX^b) and Y-linked (X^HX^H) genes present on female reproductive cards; (b) followed the incorrect idea through telophase 1 where they realised that Xby (Y-linked) and XXB (X-linked) were not the correct way to write; (c) revised the crosses diagram based on their finding: XBXb (X-linked) and cross out the Y chromosome; XBY-, X-Yh for X-linked and Y-linked respectively; (d) finalised getting the four gametes on male reproductive cell which contains the correct representation of Y-linked (y) and X-linked gene (Xb).*

The discussion of the three sections above suggested that students had different concept changes whilst they were doing an activity with the Inheritance Cards. A triangulation of data from GCA testing with interviews and observations produces an overall understanding to students' concept changes. A relationship between the tasks

they engage with during the activity and the changes in understanding can be drawn from the results and is depicted in Table 5.9.

Table 5. 9 A summary of students' concept changes on Mendelian Inheritance and meiosis and the contribution of resource in promoting the changes.

The summary was taken from triangulating data from testing, interview, observation. Column (3) sources abbreviation refers to: T= test (GCA), I=post interview, O=observation (including worksheet).

Concepts (1)	**Name (2)**	**Sources (3)**	**Concept changes (4)**	**Resource contribution (5)**
Meiosis	Omar, Faiza, Aliya	I-O	Random assortment Event of meiosis	Observing sorted cards, Labelling alleles
	Hana, Vira	T-I-O I-O	Production of gamete	Observing sorted cards, labelling alleles
	Dina, Gandhes, Karina	T-I-O	Concept of alleles/homologous chromosomes,	Labelling alleles
	Vani, Raras, Faiza, Unika	I-O	Concept of alleles/homologous chromosomes	Labelling alleles
Patterns of inheritance	Dina	I-O	autosome/sex chromosome recognition	Observing alleles on autosome/sex chromosome
	Faiza	I-O	Y-linked patterns of inheritance	Observing alleles on autosome/sex chromosome
M-M	Bona, Vani, Vira	I-O	Meiosis – Mendelian inheritance	Cards-Punnett square

5.4.4 Misconceptions during the use of inheritance cards activity: IND-2

The investigation to the effectiveness of the cards activity to promote students' concept change of Mendelian and meiosis not only informed the way it initiated students' concept change but revealed different misconceptions which were not anticipated at the beginning of the study. Therefore, the use of the cards, not only useful in promoting concept change (as shown on Table 5.9) could also act as an investigative tool for researching misconceptions. This finding constituted the explanation for the limitation of use for this version of inheritance cards. This limitation together with the suggestions from students (see Table 5.8) informed the idea for the revision to the next version of

the cards. Below are several further misconceptions found when students learn the connection between Meiosis and Mendelian inheritance using the inheritance cards.

Further examination of the students' responses to the crosses diagram revealed misconceptions related to understanding of the term 'dominant'. Karina thought that instead of two, there were three traits involved in the dihybrid cross (normal, albino, and brachidactily). In the end of her explanation, it was also revealed that she may have confused the term "dominant" of a dominant allele and misinterpreted that to the prominent trait (frequently appearing in offspring), producing statement of "it [normal trait] is dominant but recessive]".

In : Do you think that the diagram shows a cross that follows Mendelian inheritance pattern?

Ka: Uhm.. yes. One gene one trait? Yes, it is. Because the inheritance fits with Mendel… owh, do we talk about whether the pattern followed the Mendelian pattern? We could see that here are three traits involved here, normal, Brachidactily, and Albino. Yes, I think it could be said that it follows Mendelian inheritance.

In: For what reason?

Ka: Because the crosses involved three characters. It crosses AaBb with ab, and that produces uhm… 4 daughter cells, which shows normal, Brachidactily, and Albino. So, it still follows Mendelian inheritance.

…

Ka: It happens because what we cross "normal, brachidactily" with "albino, normal", since normal is recessive, it produces the offspring which are also normal, but … normal… it is dominant but recessive. And also produces Brachidactily and Albino .. uhm… .

(Karina/interview2/20 December 2016)

Mimi developed her answer based on observing that the diagram shows the phenotype ratio of 3 normal: 1 albino, brachidactily. She assumed that the three normal offspring (does not have albino or Brachidactily) are controlled by the gene for normal, which was dominant. She misconceived that there is a gene which codes for both albino and brachidactily.

In: Why do you think that the diagram show Mendelian inheritance?

Mi: Because em... what.. the crossess…produce four gametes.. which crossed and produces four gametes. Em.. it results in [the ratio of] *3:1. It forms four.. this.. four tables. So, four tables* [while point at the table of offspring]...

In: So, the thing that makes it possible is..?

Mi: Yes, because it[shows] *3 dominant 1 recessive*

(Mimi/interview2/18 December 2016)

Similarly, Yeyen also showed confusion in understanding phenotype ratio. She repeatedly refers the two independent traits (albino and brachidactily) as the two daughter cells which Mendel showed in his crosses with peas (dihybrid).

In: Well, when we use the inheritance cards, we also see it connection with Mendelian inheritance pattern. So far, what did you understand of that pattern?

Ye: Em.. Mendelian inheritance talked about the crosses between chromosomes And … Mendel gave an example of crosses on peas and … it produces two different daughter cells.

In: When you observe this diagram, do you think the inheritance of traits on this diagram follows Mendelian inheritance?

Ye: Em.. I could say so. Here, it is a cross between two parents, male and female, normal-brachidactily and albino-normal. After we got the gametes here, there are 3 different gametes, and em.. finally, there are phenotypes… em..and also two daughter cells em.. the cells have different traits here.

(Yeyen/interview2/20 December 2016)

Problems in understanding the term "dominant" as shown in two earlier cases had been highlighted by Allchin (2000). In his paper, he explained that the word "dominant" in Mendelian inheritance was frequently misunderstood as a norm trait (as in Mimi's case) or prominent trait (as in Karina's case). He indicated that this may be because textbooks that suggested the idea of "a trait appears in hybrids because it is dominant" (p.634) and because the extensive use of the term dominant with genes and alleles. To reduce the power suggested by the word "dominant" he suggested to interpreting the term "dominant" back to the understanding of it is as the phenotypic trait showed in the offspring, rather than as an allele that supresses the expression of its recessive counterpart. Apart from the possibility of students having this misconception prior to working with inheritance cards, the explanation on the Information Sheet that emphasises dominant and recessive alleles in working with Mendelian Inheritance may contribute to supporting this concept.

Similar to Yeyen's confusion of term, other students (Hana, and Bona) showed confusion when using the term 'gametes'. Both students used this term as an alternative for "genotype" to any cells at various stages of meiosis. Their confusion related to the misuse the term "gamete" is depicted in excerpt below.

*Bo: --- em.. I have a difficulty in determining the **gamete** on each card. Well, uhm… it is related to what.. er.. (laughing)its position [of alleles]. If… well, the question asked to symbolise several genetic disease, for example*

anaemia.. fanconi anaemia, and other diseases, and [I wonder] what the gametes would look like.

…

She realised her incorrect use of gamete and revised it accordingly when she continued to explain.

Bo: It was explained in the paper, but I kept forgetting. So, it was explained that ***gametes… em, no .. alleles*** *were paired up between homologous chromosomes, like that.*

…

Again, she misuses the term gamete in another part of her interview.

Bo: Oh, when ***we found*** **[how to write]** ***the gametes****, we wrote* ***all gametes in each stage*** **[of meiosis].** *The problem caused by we have to handle two cards, paternal and maternal, so we have to sort them out, there were many, and then write on them. And it is apparent that we have to write* ***gamete*** *not only at the start [card], but all over the stages* [of meiosis]*…*

(Bona/interview2/18 December 2016)

At first, Hana used "gamete" to explain genotype of cell at metaphase 1

In: You said earlier that there are cards with numbers of 1, 2, 3, and 4. Do you what the number refers to?

Ha: It is a probability of getting this form of chromosomes or ***this type of gametes*** *at the later stage*

…

She used the same term to explain genotype (allele) of cell at prophase 1

In: In your opinion, why did it happen? Why there are paternal and maternal chromosomes for each male and female card?

Ha: I think it is after… the division [segregation] *… this part is going to this part, and that is going to that part… when they were crossed, the gametes… the possibility is there is one* ***paternal gamete and one maternal gamete.*** *I think it is… So, inside one circle* [symbol of cell on the card]*… because of mating, they [paternal and maternal chromosome] could be together* [in one cell]

….

In: How do you choose what chromosomes having certain alleles in the beginning?

Ha: Based on ***paternal or maternal chromosome on that gamete****.*

…

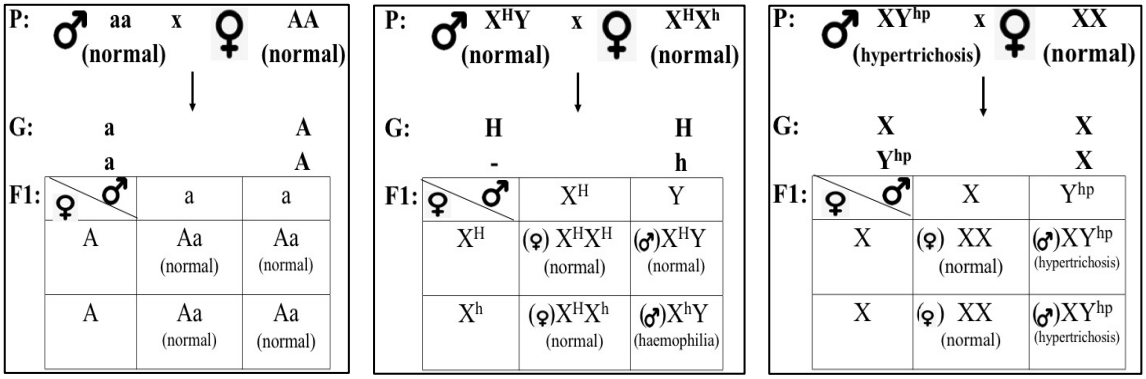
She used the term gamete to refer to the cell at the final stage of meiosis (note: this student also misunderstood stages of meiosis as part of crosses (mating)).

Ha: …At telophase 1, these [homologous chromosomes] *are separated, and then it continued the crosses* [mating]*. They* [chromosomes] *are aligned up to anaphase, when the two* [sister chromatids] *are pulled apart, so it will be only one. Then they* [the two groups of chromosomes] *are separated until telophase 2 when they become* ***four gametes****.*

(Hana/interview2/17 December 2016)

A further interview question asked of students to identify which inheritance pattern (autosomal or sex-linked) applied to the genes involved in the crosses shown on

the diagram. Students were expected to use the information provided on the diagram to determine the location of the gene and to decide from there the types of inheritance pattern for each disease-related trait. Figure 5.12 shows the way students could identify the pattern of inheritance based on what they saw in the diagram. They had practiced this when they worked with the inheritance cards, so it is anticipated that they would have learnt the principle.



(a) *(b)* *(c)*

Symbol: P = Parents, G = Gamete(s), F1= 1st Filial (progeny), A/a=alleles for albino, X^H/X^h=alleles for haemophilia, Y^{hp}=allele for hypertrichosis ♂=male, ♀=female

Figure 5. 12 The comparison of patterns of inheritance from identifying genotype on the diagram. *(a) autosomal recessive patterns of inheritance which could be identified from both parents have homologous alleles for one trait (aa, AA). (b) the X-linked patterns of inheritance which could be identified from male parent have only one allele for related trait (X^HY) as he only has one X chromosome. (c) the Y-linked patterns of inheritance which could be identified from only male has the related allele*

Interestingly, the largest proportion of students (50%) thought that they could neither identify the location of the gene nor the patterns of inheritance since information relating to these two characteristics should be provided ion the question. Only about a quarter of participants were able to identify that genes for albino and Brachidactily are located on the autosome (see Table 5.7). Among them, only Bona could provide a reasonable answer for identifying the location of the genes. Aliya could not give any justification for her choice, while Karina, Mimi, and Omar provided an incorrect reason which indicated their misunderstandings to the inheritance pattern concept. Karina showed her misunderstanding of the concept of dominant and recessive alleles (see discussion on the previous section). Mimi thought that the differences between inheritance patterns for autosome and sex-chromosome patterns was based on the number of gametes they produce.

> "[When the genes are located on autosome]*, they produced new gametes… such as these four: AB, Ab, aB, ab…when they are on sex chromosome, there will be only two gametes, such as uhm, a and b,…* [because] ***sex chromosome only has two gametes, uhm, two chromosomes, chromosome A and B****… there are only two sex chromosomes… will be A,B, for the X-chromosome will contains A, uhm, B is on maternal, A is on paternal."* (Mimi/interview2/18 December 2016)

She thought that because there are only two forms of sex chromosome, X and Y, there was no possibilities of the genes (gene for Albino and Brachidactily) being located on the independent chromosomes and having random assortment which would result in the possibilities of getting AB, Ab, aB, and ab.

Omar thought that any genes located on the sex chromosomes would not be able to be observed. His incorrect reason may be true if it was seen on the cellular level: "*any genes located on the sex cell would not be able to observe, while if it is located on the somatic cell it would be expressed on the individual phenotype"* (Omar/interview2/19 December 2016). In this case, his statement indicated that he mixed up the autosome/sex chromosome (molecular level) with the somatic/sex cell (cellular level). The same phenomenon was also shown by students who thought that a gene is located on the sex chromosome.

Another 25% participants (Azmi, Gandhes, Raras, and Vani) believed that the genes were located on the sex chromosome, the reason behind this which indicated their misunderstanding of the relationship between sex chromosome and the sex cell. Interestingly, the same confused idea was present in Omar and Vira's descriptions. Omar thought that the genes are located on the autosome. Vira could not decide on which chromosome the genes were located. Some interview excerpts below further illustrate various points of confusions with regards to the relationship between the sex chromosomes (the X-Y chromosome) and the sex cells (male and female parent). Raras thought that a sex chromosome only exists when it is involved in fertilisation. By having this idea, she actually referred to the sex chromosomes as sex cells (sperm and ovum) which are produced for the purpose of fertilisation (crosses/mating).

In: What is autosome?
Ra: Well, yah, I don't know… Ah, autosomes are cells on the body? Em.. or is it somatic?
In: What about sex chromosome?
Ra: Sex chromosome is … only on… sex chromosome uhm.. chromosome that only exist when in fertilisation, like gonosome
…

Ra: Because we want to know whether they [parents] *are normal, we can test them out, uhm.. for making sure we can do that* [the test] *with sex chromosome. When we crossed them out, we will know what offspring would come up*

(Raras/interview2/20 December 2016/)

Gandhes had an idea that if a trait will be passed to the next generation, it should be located on the sex chromosome. In this case, she considered the sex chromosomes as sex cells, rather than thinking that sex chromosomes are in all types of cells. Her notion is similar to Omar.

Ga: There are only two sex chromosomes, X and Y, and the rest are autosomes ...

Ga: Because we talked about the inheritance for albino and normal traits, well, it is generally happen uhm… sex chromosome carries the trait. And if there is a [genetic] *disorder, it should be located on the sex chromosome. … For example, albino...it happens because there is a disorder on the sex chromosome… maybe* [because] *the order of the genes is changing. So, it causes mutation.*

(Gandhes/interview2/18 December 2016)

Azmi mixed-up between the concept of sex chromosomes and sex cells. He thought that sex chromosomes were in the sex cells. If the genes on the sex cells are dominant, they will affect the overall phenotype of offspring which will be closer to the parents.

Az: Sex chromosomes uhm… are related to sex cells. If the male sex cells are dominant, then the sons will look more like his father, and the daughter looks more like her mother. (Azmi/interview2/18 December 2016)

Vira and Vani thought that X chromosome is only located in female sex cells, while the Y chromosome is only located in male sex cell. Furthermore, Vani thought that the genes were on X-chromosome because she saw more variant of gametes (AB, aB, Ab, and ab on the diagram, see Table 5.4) are produced by the female sex cell.

Vi: If the genes are Y-linked, it means the genes are on the male. If they are X-linked, they are on female.
In: Only on female? Aren't they found on male too?
Vi: No, it is only on female.

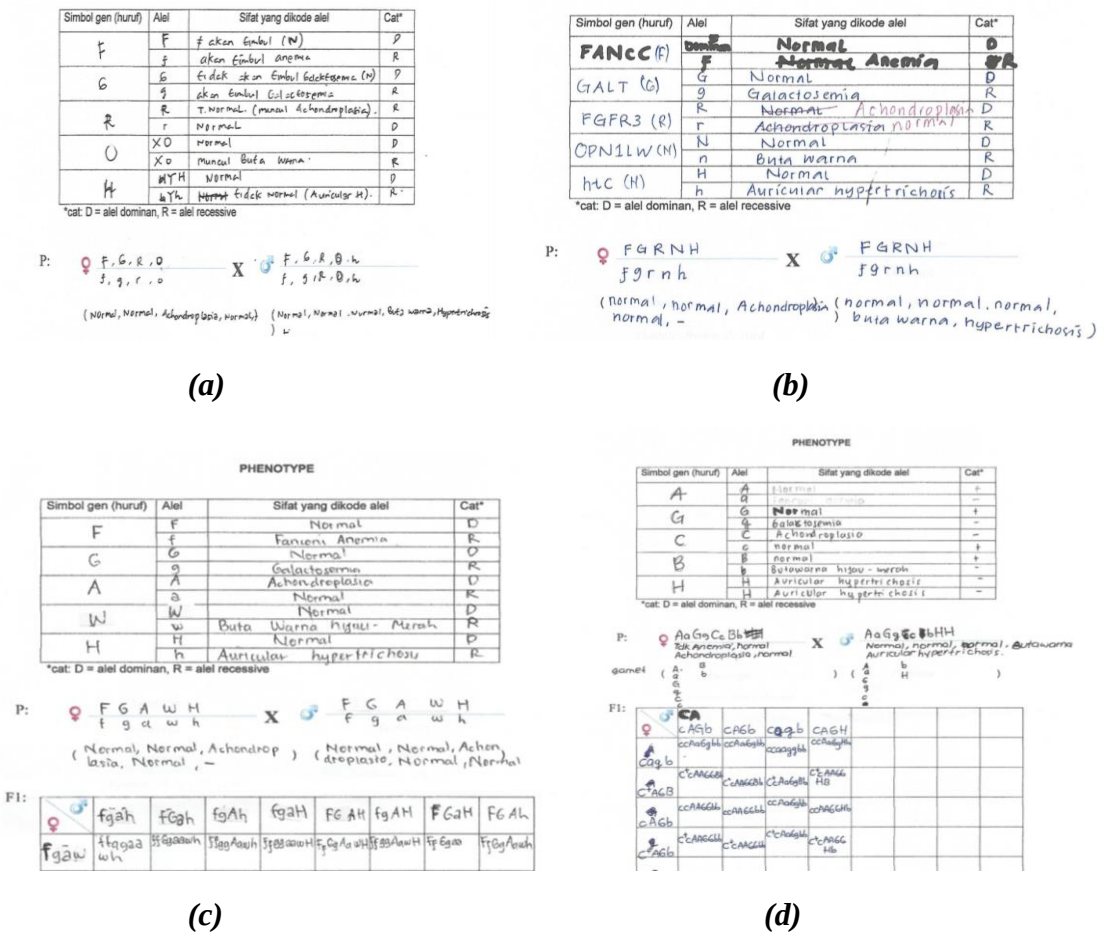
(Vira/interview2/16 December 2016)

In: Do you think they are located on the X or the Y chromosome?
Va: I think it is more likely on the Y chromosome
In: And for what reason?
Va: Uhm.. because the result of --- F1 [offspring] *mostly from the first parent [male, on the diagram]*
In: Which parent do you refer to?

Va: *this AB* [gamete which was produced] *uhm... I mean, no.. from X, yes, X.*
In: *OK. So, why do you think so?*
Va: *From the gametes. Mostly are the descendants of X rather than Y.*
(Vani/interview2/16 December 2016)

The confusion of idea of sex chromosomes and sex cell was also shown when analysing students' worksheets. Students wrote alleles of each gene on the "Crosses sheet" before writing alleles on the autosome/sex-chromosome on the cards. Figure 5.13 shows that students did not realise that there was only one Y-chromosome on male cell. Instead they wrote the two symbols for hypertrichosis (an example of Y-linked disease for this study), suggesting that the Y-chromosomes are homologous. From the same figure, it is revealed that students did not realise that there is only one X chromosome on male cell, which make male reproductive cell hemizygous. Thus, a lack of recognition of the differences between sex chromosomes (molecular level) and sex cells (cellular level), or between paternal/maternal chromosomes (molecular level) and male/female reproductive cells (cellular level) were common for students. These misconceptions misled them in when internalising the conceptual idea of inheritance, as discussed in the previous section.

The problem with differentiating sex chromosomes from sexual reproductive cells was identified from carrying out the inheritance cards activity and the interviews. It added information on the misconceptions related to inheritance. In this sense, the inheritance cards served as useful instruments in identifying these misconceptions.



(a) ***(b)*** ***(c)*** ***(d)***

Figure 5. 13 Examples of crosses diagram from four groups of IND-2 participants showing symbols for alleles for genetic disorders of three autosomal, one X-linked, and one Y-linked patterns of inheritance on male and female parents. *Their allele arrangement showed the differences from the expected answer for: (a) normal phenotype for achondroplasia on male reproductive cell should be written as homozygote recessive (aa); Hypertrichosis (h) and colour blind (o) were written on maternal and paternal chromosomes on male parent, (b) normal phenotype for achondroplasia on male reproductive cell should be written as homozygote recessive (rr); Hypertrichosis (H,h) and colour blind (N,n) were written on maternal and paternal chromosomes both on female and male parents, (c) normal phenotype for achondroplasia on male reproductive cell should be written as homozygote recessive (ww); Hypertrichosis (H,h) and colour blind (W,w) were written on maternal and paternal chromosomes both on female and male parents, (d) normal phenotype for achondroplasia on male reproductive cell should be written as homozygote recessive (cc); Hypertrichosis (H,H) was written on maternal and paternal chromosomes on male parent, colour blind (B,b) was written on maternal and paternal chromosomes both on female and male parents.*

5.4.5 Students' confusion of the symbols on the inheritance cards

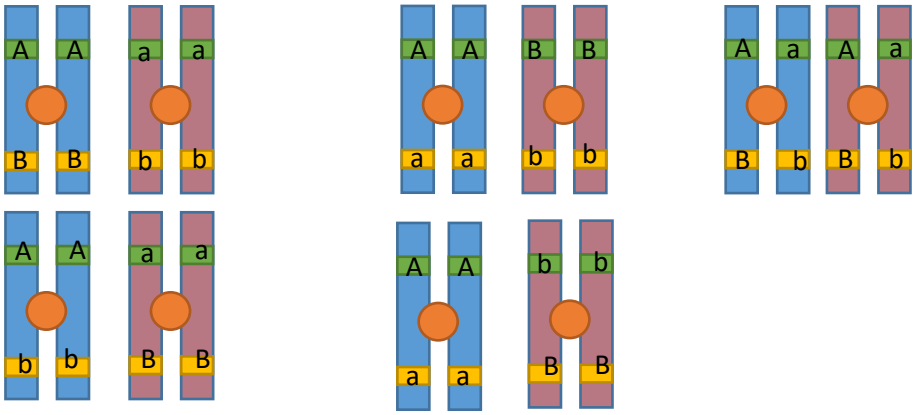
Many students had difficulty with the initial part of the inheritance card activity. This difficulty required them to spend considerable time to understanding the task-instructions which result in many groups not finishing the task within the designated time. Students lacked confidence in writing allele symbols, instead, they put the name of the gene as a symbol (see Figure 5.13, b for recorded example). It was revealed

during the observation that students thought allele symbols were specific and should have been given beforehand, so they just needed to memorise the corresponding symbol (for example, Albino is symbolised with A/a). Since they never heard many of the disease related trait presented (except for colour blindness), this made them hesitate when deciding the allelic symbol. However, when students knew that they needed to decide the symbols themselves, this activity turned to be challenging and fun to do, as articulated by Faiza, Raras and Vani in their interview (see Table 5.8, favourite parts). Thus, this difficulty needs to be monitored when students start using the inheritance cards to avoid demotivating students from completing the activity.

Students' limited conceptual understanding of paternal/maternal chromosomes, loci of gene, and homologous pairs and sister chromatids made students difficult in understanding the symbol of those concepts on the cards. This confusion contributed to the impression of the difficulty in doing the first part of the activity.

Many students made errors in writing alleles on the cards, similar to the mistake made by students in the pilot project. Two models of errors when writing alleles were identified based on students' questions during the observation which were recorded on the notes (see Figure 5.14). Students later revised their errors by doing the activity of labelling alleles on the inheritance cards (Observation notes/14 December 2016). No recorded picture of their errors can be displayed due to the fact that the allele labels are erasable, and students revised their mistake when they completed the rest of the activity.

This difficulty is thought to explain the low number of students giving the correct answer on post GCA test number 13 and 23. Number 13 asked students to identify the correct model of allelic arrangement of two genes located on the same chromosome. The expected outcome is modelled in Figure 5.14. Even though the number of students choosing error model 1 is reduced in the post test (from 35% to 6%), students tend to then favour error model 2 rather than selecting the correct model (see Figure 5.14). Analysis of GCA number 23 suggested that many students thought that alleles should be writing as error model 2, where it suggested that students confused the homologous pairs (because alleles are paired up on the sister chromatids). It is assumed that doing the activity did not help students to recognise the error in model 2 but help students to revise their misunderstandings to the error in model 1.



(a correct model) *(an error model-1)* *(an error model-2)*

Figure 5. 14 Two models of errors in assigning alleles for homologous chromosomes. *The model was built based on assigning two alleles of a gene, A and a and B and b.*

Some students mistakenly understood the symbols and the message shown on the cards. Below are descriptions of how students understanding deviated from what was intended as a message, as revealed by their interviews.

a) Confusing eight variants of gametes as eight gametes

Faiza had an idea that the 8 variants of gametes (gamete card number 1a, 2a, 3a, 4a, 1b, 2b, 3b, 4b respectively) were the eight daughter cells of meiosis (gametes).

"So from one parent [original] cell which has the combination of [chromosomes from] *its parents uhm.. paternal and maternal, there would be 16 variants, but it would depend on… well, for example we tossed the coins, so…there were 8 uhm… 1..2..3… 8, there are 8 daughter cells*. (Faiza/interview2/19 December 2016)

b) Do not understand why there were more cards in meiosis 2

Two participants (Yeyen and Aliya) thought that they have seen a greater number of chromosomes at meiosis 2 compare to the number of chromosomes at meiosis 1. This due to the fact that the number of cards showing the probabilities in gamete production are bigger than those in meiosis 1.

" I do not understand why metaphase 1 has a fewer [cards] *while metaphase 2 has bigger number." … "Well, what I know is the chromosomes and number of chromosomes are different between metaphase 1 and 2. The shape of chromosomes also different because of crossing over."* (Yeyen/interview 2/20 December 2016)

"… number of chromosomes are bigger at meiosis 2" (Aliya/Interview2/18 December 2016)

c) *Think that a and b side of the cards constitute one gamete*

> *"…So, location of gametes is the same. This one is A. And there is also picture on the card on the back side, so A and a. That is why we can get 4 gametes and each gamete contains A and a. All of them. Aa, thus A is dominant.* (Ika/interview2/17 December 2016)

Students' misconceptions informed the redesign of the task instruction for the next version. It will include an additional explanation on what the symbols means to avoid further student confusion.

An observation conducted with this group also revealed another important finding. Though, the inheritance cards were used by the group, knowledge acquisition relating to the concept of Mendelian inheritance or meiosis is different for each individual member. For example, Faiza, thought working with the inheritance cards had helped her to learn the concept of Y-pattern of inheritance (see Table 5.9), but this was not true for Sammy. The observation recording of this group activity (Observation notes/14 December 2016), showed that Faiza and Emilia were actively doing the activity, while Sammy only gave limited attention, mostly just helping to sorting out the cards. He did label alleles on the cards but did it for a short time. He did not show any interest in the activity which was shown in his perception of the benefits of doing the cards inheritance activity. He was the only participant who did not either mention the benefit of doing the activity or the problems in doing the activity. This probably relates to his limited participation in the group activity. He seemed to be unable to follow the pace of other members in understanding the purpose and rules of the task. This was evidenced from the small part which was assigned to him by other members (for example for sorting the cards and reading out the guidance). Because this was designed as group activity, the success would be on the completion of the task, rather than the individual comprehension to the concept promoted by doing the task. An involvement of all members of the group became one significant issue here. The activity of inheritance cards was actually designed to be performed by a group of three, which was likely to invite full participation from all members (Jaques & Salmon, 2007). This was due to prediction of task management, in which two members would deal with the labelling of the alleles on the cards and simulation of the fertilisation, whilst the third member would be a note keeper including being responsible for the Punnett square. However, each group has their own rules when completing the task (Jaques & Salmon, 2007), which was not completely considered when the task was designed.

5.5. Evaluation of the impact of the inheritance cards activity on students' understanding: UK

A corresponding evaluation on the effectiveness of using inheritance cards to promote students' understanding of the relation between meiosis and Mendelian inheritance had been conducted with a group of two biology/medical undergraduate students at University of Leicester. For this cohort, the impact of the booklet was evaluated through observation of how students take advantage of the booklet and the interview to reveal their understanding of the meiosis-Mendelian inheritance concepts and their learning perception toward the inheritance cards.

5.5.1. Impact of the Inheritance cards: UK

Students in UK group also experienced difficulties in understanding the instructions initially. Noah related this confusion to a feeling of insecurity because he could not anticipate the direction of the task. He initially thought that the cards demonstrated the mechanism of meiosis. He later realised the cards lead him to different idea in finding a link between meiosis and Mendelian inheritance (after he and his partner did the question part). He described his experience in the excerpt below.

> *"But I think that was more because the effect of we are doing the cards. so, it [the relation of meiosis to Mendelian inheritance] was right from the start, but I had not got my head round yet, when it is the time when we are down to the questions, I understood more of exactly what I was doing, when in other activities, you did the introduction with the video first and you go on with the cards, so I thought it was the fact that when we did the cards, I am still a bit confused to exactly what I was doing with the cards, I was not 100% sure what is the reason behind doing the... flipping the coins and things, until afterwards, looking back on it."*(Noah/interview2/2 June 2017)

Charles also shared a similar confusion at some points when he did the task. However, his confusion disappeared when he started to label alleles and observed process of meiosis taking place throughout the cards. He eventually found that meiosis cards were related to the Mendelian inheritance. This occurred when working with the resource where he observed the linked genes (two genes on a chromosome) and an independent gene (on different chromosome) and could see the aim of the task.

Despite their confusion of the aim of the task, students in the UK group labelled the alleles on the cards and correctly transferred the results into Punnett square with relatively easy. Charles even claimed that the process of labelling alleles was the most exciting part of doing the activity for him. He did have a problem in labelling alleles on the Y chromosome in the beginning. His confusion might be perpetuated by the fact that Noah had female cards with all chromosomes in pairs (including sex chromosome, XX), while his male cards are hemizygous for sex chromosomes. The hemizygous concepts were not introduced in teaching the concepts of meiosis. More effort is concentrated to teach the idea of chromosome pairs (e.g. video of meiosis on Chapter 4). This may contribute to Charles's confusion in the beginning. However, this problem was quickly sorted by Noah, who realised the rules of the cards (i.e. showing the sex chromosome) (Observation notes/30 May 2017). Their activity in labelling the cards and transferring the result to the Punnett square is presented in Figure 5.15 and 5.16 consecutively. Parallel to their relative problem-free approach to doing the activity, both students also showed the understanding of the Mendelian inheritance principle and identified the two traits (albinism and brachydactyly) correctly on the cross diagram in the interview did reflect the Mendelian inheritance. There were no further misconceptions related to meiosis or Mendelian inheritance found in this group.

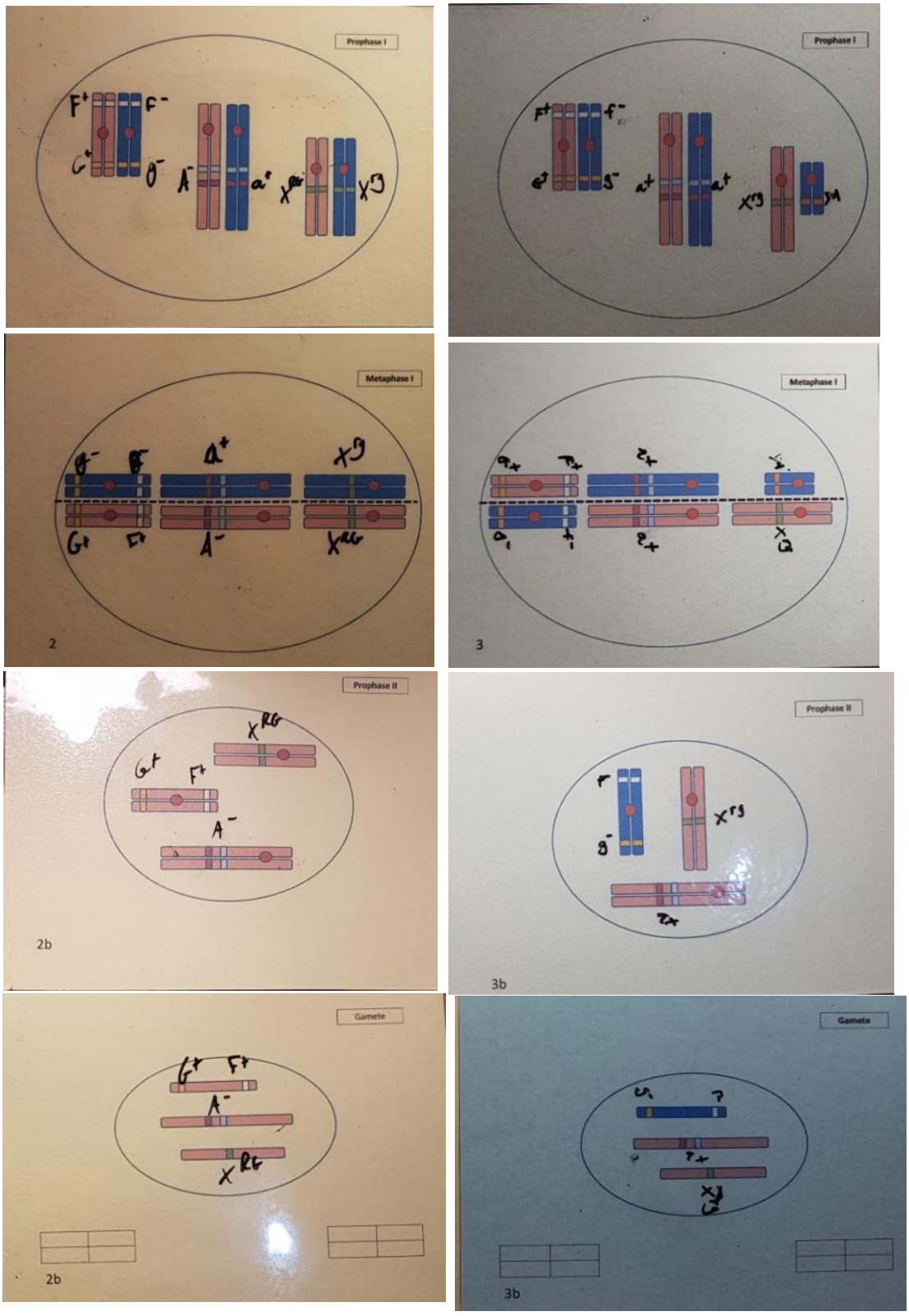


Figure 5. 15 Female (left) and Male (right) cards of inheritance showing a series of labelled alleles on autosomes and sex chromosomes undergo the gamete production through meiosis as part of Mendelian inheritance. *The pictures illustrate the way of four alleles (related to four traits) were inherited together. Students chose one gene on autosome and sex chromosome to observe how that particular gene is inherited.*

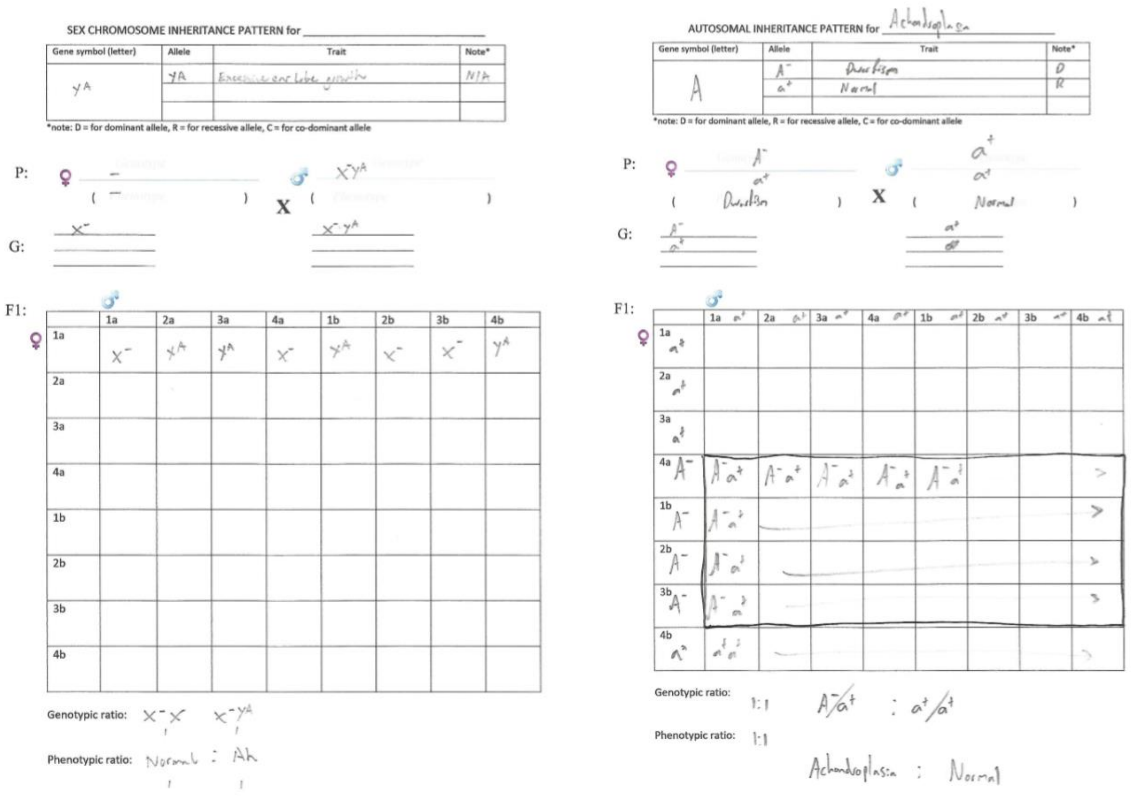


Figure 5. 16 A snapshot of crosses diagram filled out by the UK students. *Y-pattern inheritance (left), and autosomal recessive inheritance (Achondroplasia) (right). Students identified both patterns correctly.*

5.5.2. UK Students' perception to the inheritance cards activity

Despite their confusion, the two UK students found the activity benefitted them. Charles related the benefit with the effective illustration of relation between Mendelian inheritance and meiosis. He realised the connection while observing the two linked genes and an independent gene on another chromosome. He then realised that the chromosomes going through meiosis on the cards are related to the principle of dihybrid Mendelian inheritance (Table 5.10, column 4, first row). Noah thought that the inheritance cards only benefited him by demonstrating the process of production of gamete. He had a thought that lead him to the idea of the relationship between Mendelian inheritance and meiosis, however, he did not find it explicitly in the resource presentation (Table 5.10, column 4, row 6). Although he found that the explanation of Mendelian laws (law of segregation and law of independent assortment) had been given on the supplementary important terminologies related to the activity (Table 5.10, column 4, row 4), he required more explicit illustration of this principle on the cards to

benefit him in seeing the relationship between meiosis and inheritance cards (Table 5.10, column 4, last row).

Overall, students gave positive evaluations for inheritance cards. They suggested some revisions of the presentation of the cards by eliminating locus on the second autosomes which may lead them to incorrectly label alleles on that locus, and to explicitly add a step of observing Mendelian laws (by giving the related definition or explanation on its characteristic) on the worksheet.

Table 5. 10 A summary of UK students' perception to the inheritance cards (n=2). *The presenting information were based on interview analysis on the evaluation of the inheritance cards activity. A theme of students' perception is presented on column (2). Students' views were coding from the interview (column 3). An example from the interview excerpt is presented on column (5)*

Classifications	Theme	Coding	Excerpt of interview
(1)	(2)	(3)	(4)
Advantage	Visualisation of relation between meiosis-Mendelian inheritance	Presenting principle of Mendelian inheritance on meiosis	*"… particularly because we were also shown two linked genes, it is actually you can see that. So, you can see that you have genes when they are not linked, how they would go, in whatever directions, but when they are linked, they always move together. So, you can see uhm... the limit of Mendelian inheritance. So, what's fit and what does not fit, and that give you what Mendelian inheritance is by showing what is not as well….* (Charles/interview2/2 June 2016)
	Understanding concept of meiosis	Production of gamete	*"Yes, I think it is good for … yeah, having the cards in front of you, like this, you can see exactly how these represent different chromosomes, ups sorry, different alleles, one chromosome, but because uhm.. I did have written this on the cards first and to see where I went... I do not know, I have to know a bit about the chromosome beforehand, but it helps to physically show this is why one cell can have these two alleles and why they are separate and becoming gametes…"* (Noah/interview2/2 June 2016)
Favourite parts	Observe contribution of meiosis in Mendelian inheritance	Observe how meiosis works in the inheritance	*"…labelling the gene, put them in. Probably most engaging part. … It is getting to focus on one that gene has specific location. … it is just reinforcing that gene location. … when you are labelling them yourself off and then you go and see how … and if you more also just put the alternative cards, and then label the alternatives, then you can see how that gene could have been … or ended up. In gametes, whether that the same with the one over there, of course that show you where the genes are gone.* (Charles/interview2/2 June 2016)
		Observe how meiosis works in the inheritance	*Yeah... Yes, I think I knew where I was a bit more. I would say it just the fact that I uhm.. I was not 100% sure what exactly what I needed to be doing, filling up sheet and the things, and along out with the cards, so I just want to lay out the cards into meiosis, and they say different things that say to write things on the sheet, I had not get my head around the lay out of the sheet and how things were supposed to look, so i do not know... maybe it is an example on something... of how it should look, would have helped me to pick up on that faster. But once I felt comfortable with how meiosis supposed to look, I was happy to go on and enjoy the activity…..* (Noah/interview2/2 June 2016)
Disadvantage	Confused with the instruction in the beginning	Confusing points in the beginning	*The card game is interesting, but I think I was at some point confused, with the card game, but later on it did help in working out later additional chromosomes on more cards, that was helpful. That particular part … because of additional chromosomes.* (Charles/interview2/2 June 2016)
	Confused with the aim of the task	No definite link to Mendelian laws	*" I think I understood the concept, this happens causing this to happen, but specific laws to find those concepts, I am not 100% sure. Is it the law of segregation, I could not define that, I do not know what that is. But when it comes down to looking at the alleles and things, I could follow it all through, I could explain*

			if this have this trait, one homozygous or heterozygous, what the progeny is going to form, i can explain what is going to happen in second generation, things like that. I could not find the laws, that is very separate for me, have not got it down to my head yet. (Noah/interview2/2 June 2016)
Suggestions	Revision of cards presentation	Deleting the distractor chromosome	*initially it took me a while, I am not sure why. More thing, besides that, there I one chromosome that had these two genes something in the middle, but we did not, we see that as a trick… and that was… that was confusing. So that.. I think it required as to sort of disregard... sort of not two genes there and just go of it, as supposed to other chromosome that had the genes at the four ends, we know that the separate genes, we need to label them. So, you could see that this was separate. But if you choose one in the middle, that was confusing.* (Charles/interview2/2 June 2016)
	Revision of worksheet	Adding the definition of Mendelian laws	*if it was the aim of the task [showing the Mendelian inheritance], specifically understand, then definition of the different laws, otherwise it show the principle very well, uhm, but yeah.. If it is the focus of the task, then specifically that area.* (Noah/interview2/2 June 2016)

5.6. Reflection and future recommendations

The inheritance cards activity was designed to show the connection between meiosis and Mendelian inheritance. This connection was expected to be inferred by allowing participants to see the gamete making-process of selected genes through meiosis, before they randomly crossed out with gametes from the counterpart sex to produce offspring. However, with a limited number of students achieving this state showed that the intended purpose of this intervention was not fully achieved. Students were run out of time to appreciate the connections between the two concepts, either because they spent most of their time to determining symbol and labelling alleles, or because they misinterpreted the task asked them to merely solve meiosis problem. Since the connection of the meiosis and Mendelian inheritance should be discovered by students, no clear direction to observe this connection should appear on the instruction sheet. Therefore, the way to promote conceptual change of this relationship is thought to minimise time for determining the symbol and labelling alleles, and to give additional question in the worksheet on how genotype of 'gametes' on the Punnett square come from.

Despite this limitation, the use of inheritance cards activity showed many other interesting outcomes. As shown with IND-2 cohort, the use of this cards may inform the future instructor with misconceptions both related to meiosis and to patterns of inheritance. It also revealed misconceptions to a more basic ideas such as alleles, genes, sex chromosome and sex cells. Therefore, these cards are valuable as research instruments that can reveal various misconceptions for both topics. Amongst the further misconceptions found in this study was the misconceptions of alleles and inheritance that were specific for Indonesian cohort (IND-2).

Overall, the study of the development of inheritance cards showed that this resource is valuable and have the potency to challenge undergraduate students' misconceptions related to the principle of meiosis and Mendelian inheritance. However, a further revision is to maximise its effectiveness in revealing and revising students' misconceptions. The improvement focuses on the revision of the instruction and representation of the inheritance cards activity. It is thought to emphasised on the introduction of certain tasks which are:

1) In the beginning of the task, instructors need to actively ask the students whether they understand the instruction and explain if this isn't clear to the students

2) Several evaluation check-points are recommended to be undertaken to ensure students get the most benefit of the task with inheritance cards:
    a. Making the prediction of Mendelian inheritance cross based on problems given
    b. Determining symbol of alleles and labelling them on the starting card
    c. Supervising the use of coins in determining the probabilities on gamete production, determining: (a) which metaphase 1, (b) which condition (a/b) on meiosis 2

Chapter 6. Reconceptualising the gene concept through educational booklet

Overview

This chapter provides a discussion of the development and evaluation of an educational booklet in facilitating students' understanding of the concept a gene. From here onwards, throughout this thesis, this educational booklet will also be referred to as the ***'gene concept booklet'***. This educational booklet transforms the idea of instruction on the historical model of a gene into a brief written resource aims for revising students' conception in this area. This chapter begins with a rationale for focusing on advancing students' definition of the gene and the choice of a booklet to facilitate the process. It continues with a methods section which is dedicated to a more detailed explanation of the data collection procedure and analysis specific for this project and how it relates to the general methodology of the thesis. Two cycles of developing and evaluating the educational booklet are presented, each concludes with reflections and recommendations for further improvement to the booklet.

6.1. Problems in understanding gene

In genetics, the gene is a core concept which becomes the "structural and functional basis" of the subject (Cummings, 2006). The importance of the gene in genetics is highlighted in the definition of the subject as "the study of genes, including their structure, function, variation and transmission" (King, Mulligan and Stansfield, 2013).

However, advancing students' understanding of the gene concept is not easy. The advancement of research in genetics has the consequence of the progressing the definition of the gene (Pearson, 2006). A study conducted by Lewis and Wood-Robinson (2000a) showed that college students have limited understanding of the concept of a gene. The majority of students hold the classical genetic view, seeing a gene as a region located in the chromosome, or a gene as the unit factor in inheritance. Only small number of students thought of a gene as the sequence of DNA involved in the production of protein. Another problem in understanding the gene concept is pinpointed by (Mills Shaw *et al*, 2008). They found the misconceptions of this crucial concept are related to the "narrow perspective" of the deterministic nature of the gene. They found that many college students that participated in the national DNA day essay contest in the USA in 2006-2007 saw a gene as merely the determiner of trait, having the conceptions of one gene determine one trait, and lack of incorporation of the idea of multigene involvement in the trait determination.

The problem in conceptualising a gene is perpetuated by how the term gene is explained in textbooks. A quick look at the gene concept by examining the glossary of three textbook of genetics, showed that the definition may be classified into two categories. First, a gene is defined as a simple working definition. Included in this category is the definition of a gene as "the fundamental physical unit of heredity, whose existence can be confirmed by allelic variants and which occupies a specific chromosomal locus" (Klug *et al*., 2016) or as "A unit of heredity that may influence the outcome of the organisms' traits" (Brooker, 2017), as well as "An inherited factor that helps to determine a trait" (Pierce, 2016). Secondly, a gene is defined as part of molecular or chemical. Included in this category is the definition of gene as "A DNA sequence coding for a single polypeptide" (Klug *et al*., 2016), a segment of DNA that contains the information to make a functional product, either RNA or a polypeptide" (Brooker, 2017) and "a DNA sequence that is transcribed into an RNA molecule" (Pierce, 2016).

The simple definition of a gene, however, only allows a student to see a gene in the macro level (individual traits) and molecular level (a sequence of DNA). However, with the extensive research in genetics, the two definitions of gene were not sufficient to explain the richness of the gene in the study of genetics, particularly in the genomic era (Finkel, 2012; Pearson, 2006; Pierce, 2010; Slack, 2014). Introns in the DNA sequence have acted as a platform for rethinking what is to be considered a gene. They have changed the widely accepted definition of gene as "a sequence of DNA that encodes polypeptide" (Pierce, 2016) or "a molecule of DNA, present in every one of our cells, that controls the synthesis of one particular protein in our bodies" (Slack, 2014) into "the sequence of DNA that encodes RNA" (Finkel, 2012) since not all transcribed DNA will encode amino acid. Some geneticists include all exons and introns in the coding region as the structural gene, while some others widened the gene concept by including the transcription unit- promoter, coding region, and terminator- as well. The genomic era also played a role in developing gene concept. By researching the active transcription site, geneticists found out that mRNA from one gene combines with mRNA from other genes to code some specific traits. There are no limitations in the combination of mRNA, so that a piece of mRNA from a gene on a chromosome could merge with mRNA from other genes on other chromosomes. Therefore, there is a possibility of defining a gene as the sequence of RNA (Finkel, 2012; Pearson, 2006; Pierce, 2016).

The literature depicts students' existing conceptions of a gene. Extensive searching through the literature has shown that types of ideas about genes were similar between students at middle and high school, and at university level. A summary of ideas related to the model of the gene is presented in the table 6.1.

Table 6. 1. Examples of the concepts of the gene found at selected literatures that aim to explore students' conception of gene across level of education (from [1]Venville & Treagust, 1998; [2]Lewis & Kattmann, 2004; [3]Agorram, et al., 2010; [4]Dikmenli, 2009; [5]Marbach-Ad, 2001)

Model of the gene
Secondary school
- a transfer bearing particles[1]
- a characteristic determinant[2,5]
- a physical object that have an action role[2]
- a transmitted command/code that determines a characteristic[2,5]
University
Undergraduate students
- a trait bearing unit[3]
- a genetic information unit on the chromosome[3]
- a unit that creating codes for organism[3]
- a heredity unit that determine characteristic[3]
- a structure consists of DNA or the combination of DNA segments [3]
- a nucleotide structure[3]
Graduate and post-graduate students
- DNA segment (for determination of trait, for the synthesis of protein, or for both)[4]
- Alleles[4]
- A unit of heredity that determine a character[4]
- A unit of transmission (carried by a chromosome) [4]
- A unit of genetic information transmission [4]

The various concepts of the gene showed that students at secondary school and university level shared several general concepts of a gene (e.g. a gene as a trait bearing unit and a trait determinant). It also depicts that students at higher level of education may not possess a complete molecular view of the gene, but a more classical one.

In advancing students' understanding of the concept of a gene, Gericke and Hargberg, (2007) provided a framework to discuss the term gene using historical models. They divided the concepts of the gene into five historical models. Each model is developed in a specific era, based on the progress of genetics research on that era.

The first model is the gene in the Mendelian era. In this model, a gene is described as the unit of inheritance which has a responsibility to transmit or to determine a trait. The focus of the gene was more on the explaining the way genetic information was

transmitted and inherited. There was no difference between phenotype and genotype, as genotype is seen as the minuscule of phenotype which will determine the trait without any relation to the chemical or physiological process.

The Classical model focused on the work of T.H. Morgan in 1911 through the development of the chromosome theory of heredity. Using the mapping techniques, genes were visualized as relative positions on the chromosome. Each gene was seen as an indivisible particle/unit on the chromosome, as modelling in "beads on a string". Concurrent research which found enzymes involved in the determination of traits led to the idea which conceptualised the gene as substances specifying those enzymes.

When research on genetics involving biochemical reactions was growing, the focus of genetics also shifted from transmission to gene function to biochemical nature of the gene. The biochemical-classical model focused more on defining the gene based on its function in terms of the production of specific enzymes and its relationship to the determination of phenotypic traits. The revision of the previous model was based on the evidence that the products of genes are not always enzymes but could also be proteins. This shifted the idea of one gene, one enzyme into one gene, one protein.

Later, with the discovery of the structure of DNA in 1953 by Watson and Crick, the material basis of inheritance was applied to genes, and led to more definite terms of genotype and phenotype. With the molecular basis of genetic information identified, the model of genes as particles shifted to genes as coding for information. The neoclassical model began to combine the molecular understanding of genetics to Mendel's ideas about inheritance. At this time, a gene became to be understood as a unit of information that functions in coding for an RNA messenger, which acted as a template for specific polypeptides.

Following the 1970s, as knowledge progressed, inconsistencies between the neoclassical model and recent work began to mount, and failed to explain other phenomena, such as alternative splicing, complex promoters, overlapping genes, and other processes. Thus, Gericke and Hargberg (2007) delineated the need for a more modern view of a gene and its function that is more open and complex. Under the modern model a general description can no longer exist, but rather different contexts for different areas of study. According to Pearson (2006) and Gericke and Hargberg (2007) genes no longer function to produce a single polypeptide, but instead fall within a number of other categories of genes such as genes that produce enzymes, genes with a regulatory function, or genes that produce specific non-soluble structural units. Figure

2.1 is the concept map developed by Gericke and Hargberg, (2007) to outline the key features of the gene concept. In this model, gene function is understood as more of an actor within a larger system in which the information follows from DNA to RNA to Polypeptides. In other words, what is commonly termed as the Central Dogma of Biology or gene expression, which is the process by which molecular information encoded in DNA is transformed into a functional unit in a biological system.

Smith, Mike U. and Adkison (2010) updated the model of the gene by dividing the modern concept into two models of the gene, the human genome project (HGP) model and the encyclopaedia of DNA elements (ENCODE) project. They also revised and added some information with regard to the model of the gene that had been developed by Gericke and Hargberg (2007), specifically in addressing the importance of environmental factor and the operational definition adopted by geneticist in a discussion that involve the term "gene". Figure 6.1 shows the progressing definition for the model of the gene adapted from Smith and Adkinson (2010).

6.2. The basis for developing educational booklet of the concept of the gene

Despite its role as the central concept of genetics, the gene concept is mostly discussed as an integrated part of other topics in the curriculum. For example, the concept of a gene as a factor or a heredity unit is brought up when explaining the mechanism of Mendelian inheritance. A different concept of a gene, e.g. gene as a segment of chromosome is pointed out in the discussion of cell division, mitosis and meiosis.

A booklet is "a very thin book with a small number of pages and a paper cover, giving information about something" (Cambridge dictionary[a], 2019; Soanes, 2008). A booklet shares similar description with pamphlet but differs from a leaflet in only the number of pages. All information in a leaflet has to be printed on a sheet of paper (Cambridge dictionary[b], 2019), whilst it could be printed on several pages in a booklet.

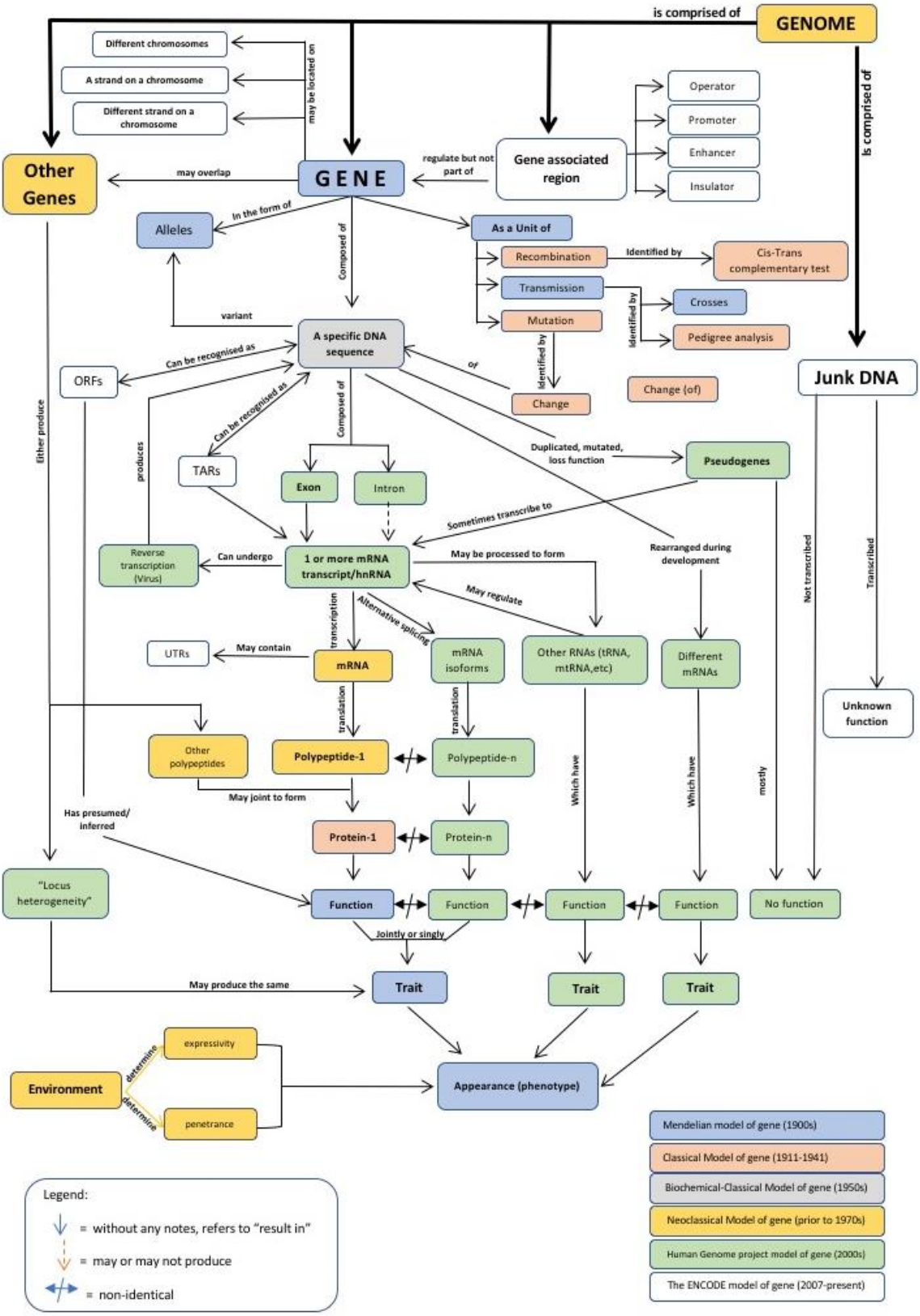


Figure 6. 1 A resume of the evolving model of gene adapted from Smith and Adkinson (2010). *Each colour showed the era when the specific gene-related-terms are introduced. For example, the term "gene" and "trait" (blue box) had been introduced since the Mendelian model of gene, while "TARs" (white box) is newly introduced in the ENCODE model of gene.*

There is no general definition of educational booklet, however, in this project, the term is defined by combining the meaning of the "educational" and the "booklet". The term "educational" refers to any object that is intendedly constructed to inform or to instruct subject (thefreedictionary, 2019), or to teaching something (Longman active study dictionary, 2008). Based on the above definition, the educational booklet is delineated as the thin book that is developed intendedly to assist the instructional process.

Since a booklet allows presentation of information to be divided into several pages, it fits the requirement to deliver the information of the progressing historical model of the gene. A gene model for each era could be briefly discussed as separate section or chapter. At the same time, the whole sections/chapters maintained its focus in communicating the concept of the gene.

6.3. Specific methods for the development of the booklet of the concept of the gene

The general methodology for conducting this study refers to the action research design approach, an iterative process of development and evaluation, as described in detail on Chapter 3 Section 3.2. This section is dedicated to describing the specific research problems, data collection and analysis related to the development of this educational booklet.

6.3.1. Specific research questions

Research questions for this specific study of developing the booklet of the gene concept stemmed from the larger context of studying the way targeted teaching resources addressed students' misconceptions (see Chapter 1, section 1.3). There are four specific research questions focused on examining the effectiveness of the educational booklet in changing students' misconceptions (Table 6.2). Following the general methodology for developing resource in this thesis, the evaluation of booklet involved the two groups of students who studied in Indonesia and UK in one of the development cycles. Those questions specified the data collection method in term of the type of the test used in this study and the way of analysing the data, as will be specified in section 6.4.2. Table 6.2 shows a mapping of specific research questions with specific methods in data collection.

Table 6. 2 Mapping research questions with types of data used to study the effectiveness of the gene concept booklet

Research questions	Source of data			
	MCI Test	Observation	Interview	Researcher journal
RQ 1. How is information regarding common misconceptions used to develop the gene concept booklet?				√
RQ 2. What are university students' existing perceptions of the basic concepts of a gene?	√			
RQ 3. In what ways does the gene concept booklet modify university students' misconceptions of a gene?				
RQ 3.1. What misconceptions are altered after use of the gene concept booklet?	√		√	
RQ 3.2. What elements of the gene concept booklet contribute to the change?		√	√	√
RQ 3.3. How do university students perceive their learning experience with the gene concept booklet?		√	√	
RQ 4. Are there any differences in the way university students in Indonesia and the United Kingdom perceive the benefits of the gene concept booklet?	√	√	√	

6.3.2. Research flow and timeline

This study followed the general procedure for developing and evaluating targeted teaching resources as described on Chapter 3 section 3.1. The process of development and the evaluation of the concept of the gene booklet involved two cycles of action research. In the first cycle, the evaluation stage involved a group of Indonesian students (IND-2), and a group of UK students (UK), while the second cycle involved a cohort of Indonesian student in the following academic year (IND-3) (see section 6.3.3 for further details about the participants). A detailed procedure for evaluation was expanded from the general procedure to incorporate the way the educational booklet was utilised in the learning process. Figure 6.2 shows a summary of the research design and a flow diagram for the research in this particular study. The project timeline shows the length of time dedicated to each stage in the development of the gene concept booklet (Figure 6.3), meanwhile the detail event related to the evaluation stage of the educational booklet is given in Table 6.3.

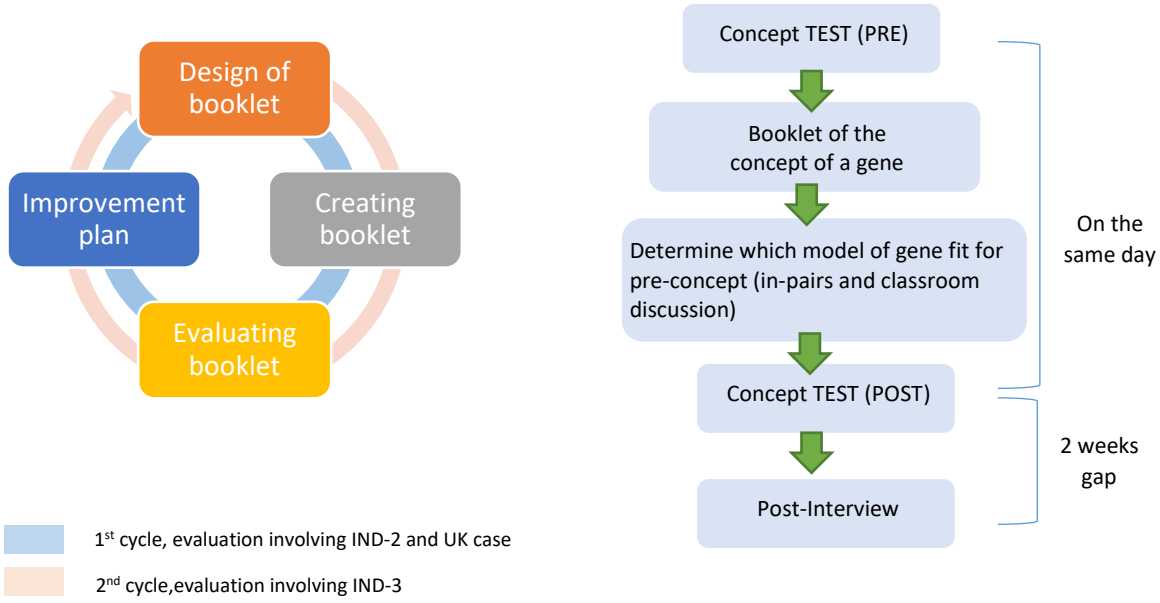


Figure 6. 2 A summary of research design and the flow of the booklet evaluation stage. *(a) study research design with two cycles. Evaluation of booklet in cycle 1 involved IND-2 and UK cohort, while in cycle 2 involved only IND-3 cohort. Each cycle consists of stage of design> creating>evaluating and reflecting (b) a flow of the evaluation stage for each cohort showing the activity they did related to the method of data collection (test, observation, and interview)*

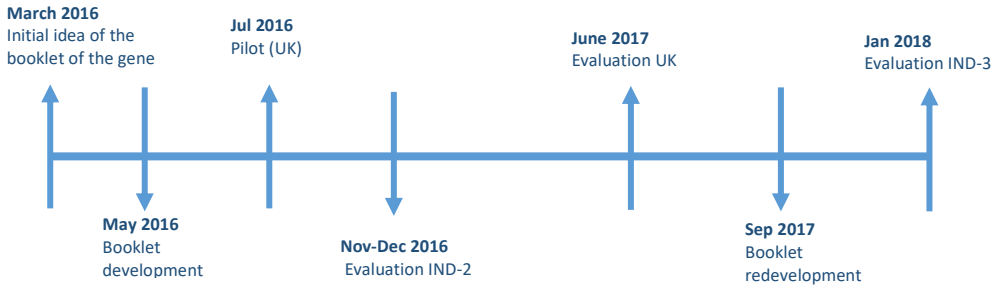


Figure 6. 3 Research timeline showing significant events in the development of the booklet of the gene

Table 6. 3 Data collection timetable for the evaluation of the booklet of the gene

Stage	Date	Activities
1st	**INDONESIA SECOND COHORT (IND-2)**	
	21 Dec 16	Gene Test (PRE)
		Teaching session/observation to students' interaction with the booklet
		GeneTest (POST)
	22-24 Dec 16	Interview
	UK COHORT (UK)	
	12 Jun 17	Gene Test (PRE)
		Teaching session/observation to students' interaction with the booklet
		Gene Test (POST)
	16 Jun 17	Interview

2nd	**INDONESIA THIRD COHORT (IND-3)**	
	23 Jan 18	Gene Test (PRE)
		Teaching session/observation to students' interaction with the booklet
		Gene Test (POST)
	26-30 Jan 18	Interview

6.3.3. The context of study and participants

This study was conducted in two cycles of a complete four stage of action research. Following the action-research framework for this study (Chapter 3, section 3.2), there are two interrelated studies for this project. The first study is related to the design and the development of the booklet of the concept of the gene (the action part), whilst the second one is associated with the evaluation of the impact of educational booklet in altering students' misconceptions (the research part).

The evaluation stage involved three groups of students, two group of Indonesian students (IND-2 and IND-3) and another group of UK student (UK) (see Chapter 3 section 3.3 for detail characteristic of participants). All participating groups (IND-2, IND-3, and UK) were in the process of completing the genetics module when the study was conducted. Table 6.4 shows the number of students involved for each group.

Table 6. 4 Number of participants involved in the evaluation stages of the gene concept booklet

Case	*Academic year*	*Number of students consent to participate*	*Number of participants*
IND-2	***2016/2017***	***25***	***21***
UK	***2017/2018***	***2***	***2***
IND-3	***2017/2018***	***10***	***9***

Students were invited to attend an informal teaching session using the gene concept booklet. The "test of the concept of the gene" was given to participants before (pre-test) and after (post-test) the teaching session to measure the impact of the booklet in addressing students' misconceptions. Students' interaction with the resource was observed during the session and recorded as a notes. Within a week of the session, students were interviewed about their concept of the gene and their learning experience using the booklet. Only students who had gone through all the evaluation stages (as described on Figure 6.2.(b) are regarded as participants, due to the requirement to triangulate the data.

6.3.4. Data collection, analysis and interpretation

In general, the data collection, analysis and interpretation for this project followed the thesis methods in collecting and analysis data described in Chapter 3 section 3.5 and 3.6. This section is dedicated to give a more detail explanation to specific data collection and analysis relating to the test instrument (concept of the gene test). Other methods of data collection and analysis which was not described in this section followed the general procedure for thesis.

Data collection

The instrument known as the "test of the concept of the gene" was developed to explore students' conception of a gene. The test contains one question about what students understand about the gene. Students were asked to visualise their self-definition of gene by creating two external representations: verbal and pictorial (drawing/diagram). The test was constructed based on open ended question strategy to explore students conceptions of a gene as demonstrated by (Lewis, Leach and Wood-Robinson, 2000a; Wood-Robinson, Lewis and Leach, 2000; Dikmenli, Cardak and Kiray, 2011), although the previous studies did not include the requirement to express the idea of the gene using pictorial representation. Both verbal (written) and pictorial (graphical) representation are the way of identify how people organise and represent the world inside their mind (mental model) (Eysenck and Keane, 2000). Asking students to represent their mental idea of gene using two external representations provides a better opportunity to interpret their conceptual idea as well as to identify misconceptions regards the subject.

The term "test" for this instrument is not completely accurate, unlike a common constructed test, the open-ended question were not intended to measure the cognitive skill or to award a score as described by Cohen, Manion and Morrison (2011). For this purpose, it may better be defined as a questionnaire as it is "… a series of questions, statements or items are presented, and the respondents are asked to answer, respond to, or comment on them in a way that they think best." Cohen, Manion and Morrison (2011) directly classified the open-ended question as questionnaire, while Lewis *et al.* (2000) and Dikmenli *et al.* (2011) did not explicitly categorised it as a questionnaire. The adoption of the term "test" for this instrument was done for its practicality since the open-ended question was given before and after the working session with the

educational booklet and was utilised to assess the change of how they understand the concept of the gene.

Data analysis

Data analysis run in two stages. The first stage focused on searching the key-terms in students' verbal and pictorial representations of a gene which substantiate their understanding of a gene, while the second stage focused on determining students' specific historical model of gene. Figure 6.4 displayed the complete sequences of data analysis and interpretation for the test of the concept of the gene.

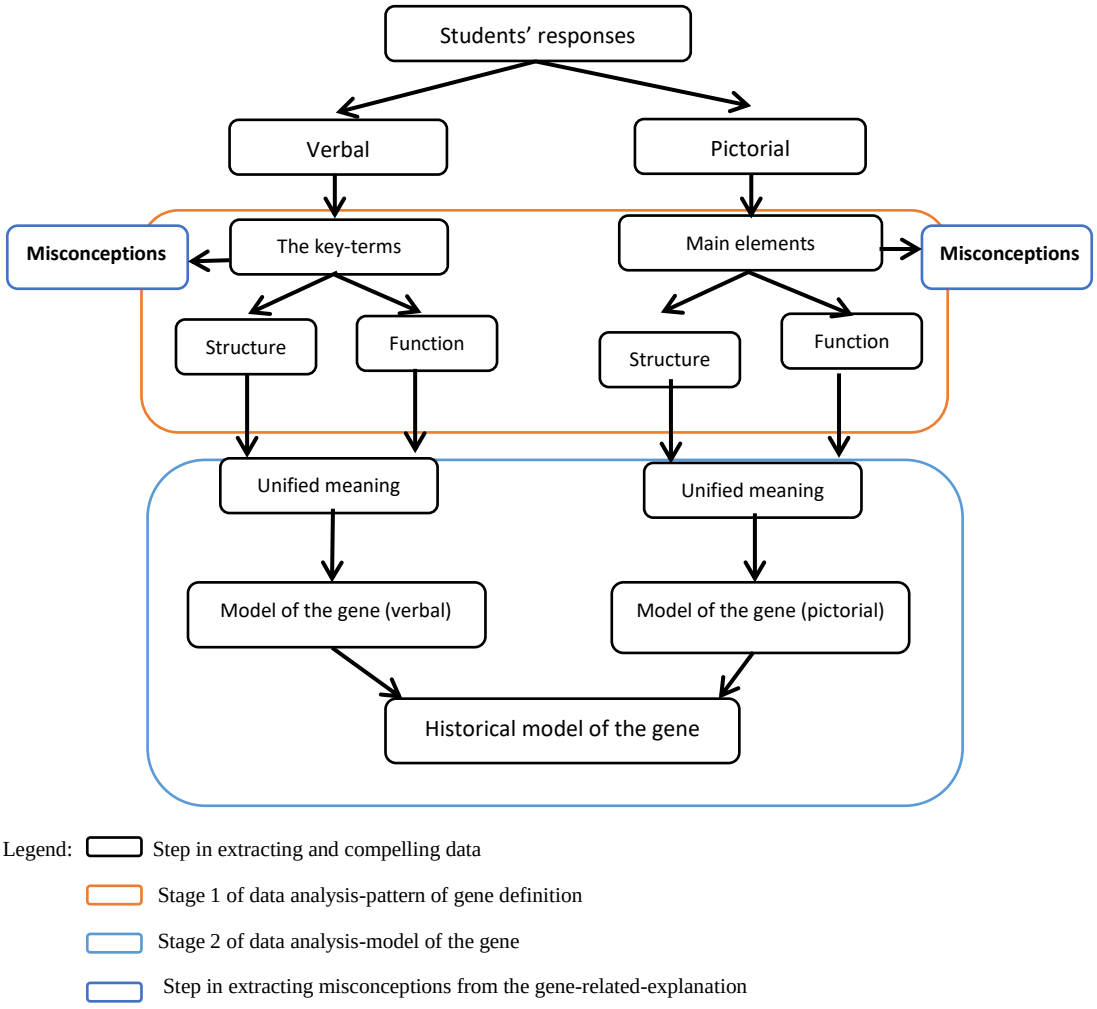


Figure 6. 4 The complete sequences of data analysis and interpretation of the test of the concept of the gene. *Data is analysed in two stages. Misconceptions on the supporting element/term are recorded during the analysis on the first stage. The final stage of analysis results in the categorisation of historical model of the definition of the gene.*

In detail, the first stage of data analysis involved the searching for the general pattern of what students conceptualised as a gene. In analysing and interpreting data, the

focus was on the ideas and understanding of the concept of a gene, rather than whether the students gave scientifically correct answers. Therefore, the analysis presents the 'ideographic approach' to coding students' responses as demonstrated by Lewis, Leach and Wood-Robinson (2000a). Ideographic is an approach that focuses on understanding subjective and individual unique views (Cohen, Manion and Morrison, 2011)). Students' ideas will be analysed based on their response to the question. Students' ideas of the gene from verbal and pictorial responses were coded independently to find similarities and differences in the pattern of ideas from both approaches. Both verbal and pictorial data were categorised into two groups: the structure, and the function of the gene. These two categories were the main characters to distinguish the historical model of the gene proposed by Gericke and Hagberg (2007), and Smith and Adkison (2010). Verbal data analysis was conducted through examining students' category-related-key-terms, whilst pictorial data analysis was conducted through extracting elements of the picture and identifying the elements labelled as a gene (Table 6.5). In this first stage of data analysis, any misconceptions relating to the supporting concept (e.g. the structure of the chromosome, or the mismatch of complement on double-stranded DNA) from both verbal and pictorial descriptions of the gene were recorded.

Table 6. 5 Steps in analysing students' drawing concept of the gene

Steps	Detail of action
Step 1	Identifying elements of the picture based on the common symbol or based on the additional notes given to the picture
Step 2	Identifying element of the picture that have been labelled as "gene"
Step 3	Categorising element with "gene" labelled into one of two groups: structure of gene or function of gene - If there is no label of "gene" on the picture, then the term gene is extracted from the verbal definition - If there is no label of "gene" on the picture, and no explanation in the definition of the gene related to the picture, then the picture is categorized as the "associated element of gene"
Step 4	Connecting the relationship of all elements of the picture to generate the unified meaning of the idea of the gene

The second stage of data analysis involved the categorization of the historical model of the gene. This step was conducted matching individual student's key-terms of gene from the first stage with those specified each historical model of gene. Data from verbal and pictorial representation were combined to interpret the complete categorisation of the model of the gene. If students held two gene models, both were coded and named as a hybrid conception of those two models of the gene.

6.4 The design and creation of the gene concept booklet

This section discusses the initial design and construction of the gene concept booklet. The design stage focused on determining the instructional purpose of the booklet, analysing targeted common misconceptions that would be dealt with, and planning the presentation of the educational booklet. The construction stage focused on creating the booklet and related task-activity.

6.4.1 The initial design of the booklet of the concept of the gene

The main problem in understanding the gene concept stems from the limitation of adopting the modern model (molecular view) of a gene and a tendency to preserve the classical model of a gene, i.e. a gene is seen as a particle at cellular level (chromosome) (Dikmenli, Cardak and Kiray, 2011). The problems of upholding the classical view of the gene was frequently found in other research involving students at middle and high school level (Kalas *et al*, 2013; Lewis and Kattmann, 2004; Lewis, Leach and Wood-Robinson, 2000b). Furthermore, students may also hold a confusing gene concept that combines the molecular view of a gene with the classical one lead to the oversimplification of definition into a deterministic idea of a gene (one gene determines a character). Dos Santos, Joaquim and El-Hani (2012) found the relation between the hybrid deterministic ideas of gene with misleading information presented in a high school textbook in Brazil. To overcome the problem, Agorram (2007) recommended development of an activity which enables students to evaluate their conception of a gene to improve their understanding.

Gericke and Hargberg (2007) had proposed a historical model of the gene that serve as a platform in teaching genetics using the epistemological approach of understanding of gene. Smith and Adkison (2010) updated the historical model of the gene further by extending the historical model to include the latest definition of the gene, informed by the Human Genome Project (HGP) and more recent genomic research (Post-ENCODE). To include the two latest model of the gene, the HGP model, and the Post-ENCODE model, provided students with an up-to-date definition of the gene which is expected will encourage them to conceptualise the gene based on those models (Falk, 2010; Pearson, 2006; Gerstein *et al*, 2007; Portin and Wilkins, 2017; Griffiths and Neumann-Held, 1999).

A booklet has the potential to facilitate the presentation of the evolving concepts of a gene which was outlined in the historical model of the gene. In so doing, students

will be given an opportunity to understand the relation between the advancement of research in genetics with the evolving conceptualisation of a gene. At the same time, students are invited to evaluate their existing understanding of the gene and ultimately will expand their concept of the gene. This thought provided the scaffolding of the design of the booklet. Below are steps in designing the educational booklet of the gene.

1. Designing the overall concept of the booklet

The historical evolution of the model of the gene (Gericke and Hargberg, 2007) served as the basic scaffolding to present concepts in the booklet. Each page/sheet was dedicated to discussing specific information regards to each historical model of the gene. Thus, each page was named after the model of the gene. In total, there were five dedicated sections of the booklet.

A comparison with the updated version of the model of the gene (Smith and Adkison, 2010) was used to add the latest understanding of the gene concept which was incorporated into the two latest sections on the booklet. The author divided Gericke and Hargberg's latest model of gene (modern model of gene) into two models for the gene: a human genome project (HGP) model and a post-ENCODE (encyclopaedia of DNA elements) model. They also provided the estimation of year for each model of gene which then used as a reference to present the related genetics research that lead to the definition of gene for each era.

By comparing the occurrence year between neoclassical model (prior to 1970) of Gericke and Hargberg (2007), and the HGP model (around 2000) of Smith and Adkinson (2010), showed a gap of years (1970-2000) where there was not any revision to the model of the gene. However, the years between 1970 and 2000 were a golden time which considerable amount of research in genetics had been carried out that culminated around 2000 (Griffiths and Neumann-Held, 1999). Therefore, this range of years was used to present the 'modern model' of the gene as proposed by Gericke and Hargberg, (2007) which focused on the adoption of gene as the coding sequence or ORF (open reading frame) of DNA. In consequence, there were seven dedicated sections; each section refers to one historical model of the gene (Table 6.6)

Table 6. 6 Key-terms for describing the model of the gene in each chapter of the educational booklet of the gene (adapted from historical model of gene (Gericke and Hargberg, 2007; Smith, Mike U. and Adkison, 2010)

Historical model	Structure/ operational definition	Function	Important notes/entities	Organisational level
Mendelian (early 1900s)	A factor/a unit that exists in two forms (alleles)	Inheritance/ passive transmission	Genotype (gene) is also a phenotype (character)	Symbolic
Classical (1911-1941)	A dimensionless point/a segment/a locus on a chromosome. Genes on a chromosome looks like "beads on a string"	To determine a definite character/trait	Gene (an enzyme/acts as enzyme) is involved in the determination of character/trait	Cellular
Biochemical (prior to 1953)	A particle/a segment of chromosome *(notes: it does not link to DNA double helix structure)*	To produce an enzyme	Gene produces enzyme (which later involve in the determination of character/trait). *One gene-one enzyme hypothesis*	Cellular
Neo-classical (prior to 1970)	A genetic material/ sequence (segment) of DNA consisting code/ information/ instruction acting as a template and transcribed into mRNA and codes for a single polypeptide	To determine the sequence of amino acids in a resulting protein	Gene (DNA) produces mRNA produces polypeptides/enzymes (The central dogma of biology) *one gene-one polypeptide hypothesis*	Molecular
Modern (1970-2000)	A segment of DNA containing an open reading frame (ORF): start codon-polypeptide coding region-stop codon, either as putative gene (prediction/ computation) or the already known protein encoding gene	To determine the sequence of amino acids in a resulting protein	Gene (DNA) produces mRNA produces polypeptides/enzymes (The central dogma of biology)	Molecular
HGP (around 2000)	An ordered sequence of nucleotides (DNA) located in a particular position on a particular chromosome that encodes a specific functional product (protein or RNA molecules)	To determine various products: polypeptides, enzymes, structural (non-soluble) protein, regulatory gene, RNA molecules	The definition incorporated: split genes, nested genes, alternative splicing, complex promoters, polyprotein genes, multiple adenylation, enhancer, overlapping genes, trans-splicing	Molecular
POST-ENCODE project* (2007-present)	A genomic sequence (DNA/RNA) encoding functional products that could be overlapping)	To determine various products: polypeptides, enzymes, structural (non-soluble) protein, regulatory gene, RNA molecules	Focus on the products, number of functional genes are correlated with the associated product	Molecular

*THE POST ENCODE (Encyclopaedia of DNA elements) definition of gene has recently been proposed and has not been accepted as the consensus paradigm definition

2. Deciding the content for each page of booklet

The content for each page was developed through integrating research in genetics that support the concluding model of the gene. Much literature (e.g. Gerstein, 2007; Portin, 1993) served as the sources for developing the pages, however, the basis was the historical model of the gene and the updated version. Table 6.6 showed the key-terms included in developing content for each era.

To support the conceptual formulation process, a pictorial representation of the gene was inserted on each page. This additional pictorial representation acted to enhance the mental model, it has been suggested that the latter is built on two basic types of representation, verbal and images (Eysenck and Keane, 2000). The selected images or drawings were chosen based on how they represented the conceptual model of the gene specific for each era.

3. Determining a title of booklet

A projected title for the booklet of the gene concept was designed to include the scope of the content and the purpose of helping students in redefining the gene. To cover those issues, the proposed of the booklet name was "A brief definition of the gene".

4. Producing the booklet

The technical problems were related to the material and the way each chapter combined together to be a booklet. Booklet was designed to be printed on 80-gram A-4 size paper to count in the space needed to insert a picture. The weight of the paper thickness was so it was reasonably durable, and not too thick, so it would be easier and cheaper to distribute.

6.4.2 The construction of booklet and the pilot study

The production stage of the booklet of the gene followed the selection and development of content (design), except for changing the concluding statement (last part of content) into a summary (the first part of content). The booklet consisted of seven sections, each section was printed on a separate page. The seven sections were named for the models of the gene (see Table 6.6). The content for each page was developed through exploration of supporting material from commonly used genetics textbooks (Hartl, 2014; Klug *et al*, 2016), articles related to the concept of the gene (Forissier and Clément, 2003; Falk, 2010; Pearson, 2006; Gerstein *et al*, 2007; Burian, Richardson and

Van Der Steen, 1996; Burian, 2013; Bartol, 2013; Castéra *et al*, 2008), and popular science books which focused on discussing the concept of the gene (Slack, 2014; Finkel, 2012). Booklet was printed on the 80 g A-4 size paper as planned. The title of the booklet was preserved as "A Brief Definition of a GENE" to emphasise the concise explanation of the idea of the gene. Figure 6.5 showed the implementation of the design to the development of the booklet. See also Appendix D-1.

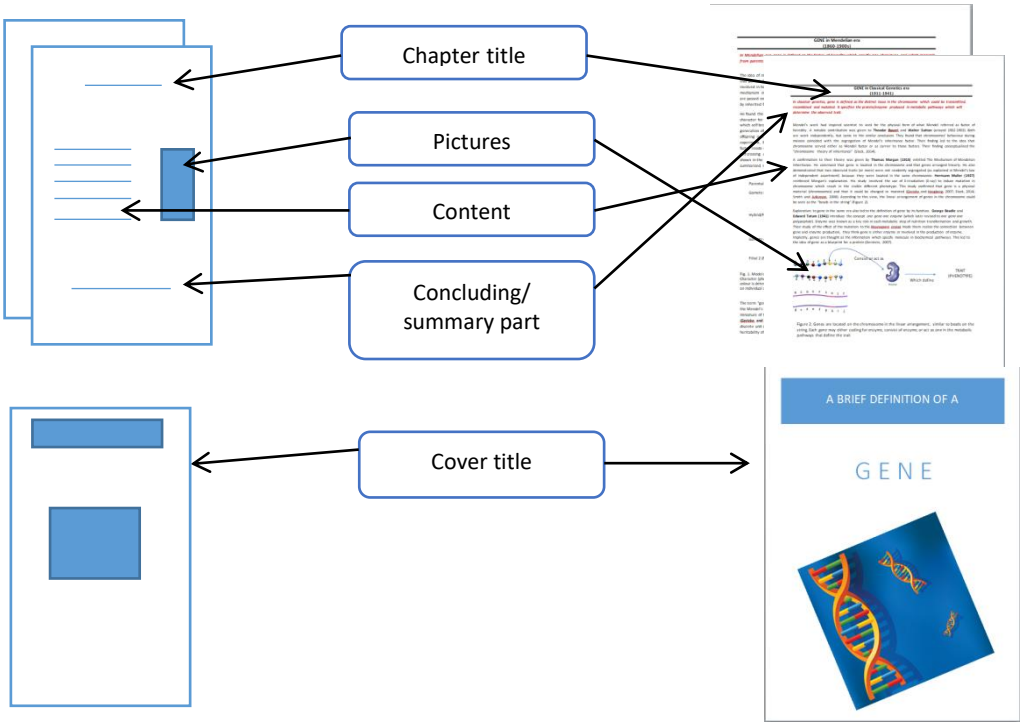


Figure 6. 5 The implementation of booklet design into the booklet of the concept of gene version 1

6.5. Evaluation of the impact of the gene concept booklet on students' understanding: IND-2

The first evaluation of booklet involved two groups (IND-2 and UK). First, the discussion will focus on discussing the existing concepts of the gene held by the Indonesian student cohort (IND-2), and the way the booklet challenged their misconceptions and promoting their model of the gene. The next section (Section 6.6) discuss the same topic, but with a group of UK students.

6.5.1. Indonesian Students' (IND-2) existing conception of gene

Students' initial ideas about the gene served as the basis for measuring how the educational booklet addresses the misconceptions which obstruct them in achieving a fuller conceptual understanding. Both verbal and pictorial representations from the concept test of the gene were used to explore students' views of the gene. When conducting the analysis, some interesting misconceptions including the misuse of terms, misrepresentations, and the misinterpretation of the relation between gene and DNA were revealed, described below.

The higher frequency of students holding the concept of gene as the classical model was revealed by analysing their verbal and pictorial representations of the gene in the pre-test. Data which has been analysed is presented as the word frequency and the ideogram of participants' idea of a gene (Figure 6.6).

The word frequency or the word cloud is one of the features provided in the NVIVO12. It functions to depict the number of words cited in discussing a specific topic. In this term, word frequency served similar purpose with word association task (e.g. (Dikmenli, Cardak and Kiray, 2011). Since students had already been given a task to verbally describe a gene, the words that they used in defining genes gave similar results.

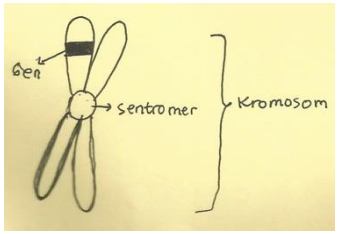
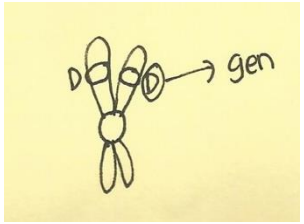
Figure 6. 6 Common words used by Indonesian students (IND-2; n=21) to verbally define a gene prior to learning with the the gene concept booklet. *The greater frequency is shown by the bigger size of words. Students' original responses were translated into English prior to analysis. The word "gene" was removed since it was the word in question. Also, conjunctions and other determiners were removed.*

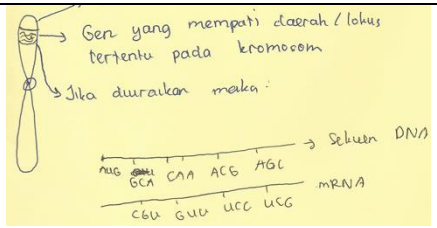
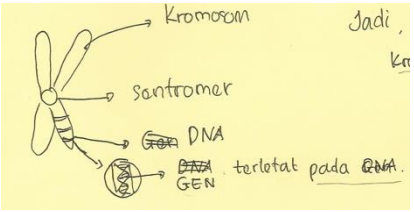
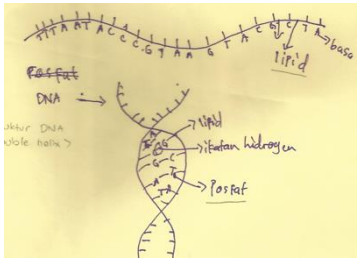
Figure 6.6 shows word frequency analysis for IND-2 students existing verbal concept of gene. The figure showed various terms used by IND-2 students in defining the gene. The three most frequent words used by this cohort are genetic, chromosome and trait/characteristic. The two latter words (chromosome and trait) are commonly related to the classical concept of genetics, such as indicated in a sentence describing classical genetics in a dictionary of genetics, *"... gene is ... a particle or a unit of inheritance that occupies a specific location (locus) on the **chromosome**, and has a function mostly to manage the **phenotypic appearance***" (author's emphasis in bold) (King, Mulligan and Stansfield, 2013). The second group of most frequent associated words are of offspring, parents, descendants and inheritance. Words in the second group also commonly related to classical view of genetics, particularly in describing transmission (inheritance) of gene from parents to descendants (Portin and Wilkins, 2017). Terms that related to molecular view of a gene, such as DNA transcribe, translation, and nucleotides, are found on the word frequency, but they are less common.

The classical view showed a gene as a part or a segment of chromosome. The representation of a gene as a segment on a chromosome was the legacy of the Morgan's school when they showed that genes lie on a chromosome in a linear fashion (Slack, 2014), symbolised by beads on a string, which became common model for classical genetics (Gericke and Hargberg, 2007). The representation of genes on a chromosome was dominated students' pictorial definition of gene, except for (Karin (pseudonym) who drew the structure of double helix DNA. Although there are some students (for example Bona and Omar, see Table 6.7) tried to incorporate structure of double helix DNA in their pictorial definition of gene, they still preserved the relation between gene on a chromosome on their definition. Several representations of students' image of the gene are presented on column 5 of Table 6.7. For an example representation of pictorial definition of gene for this cohort and the coding analysis process, see Appendix D-2.

Table 6. 7 Historical models of the gene of Indonesian students (IND-2, n=21) based on their individual verbal and pictorial definition of gene

The table shows the historical model of the gene constructed from students' verbal and pictorial conceptualisations of a gene. The questions were given just before students used the booklet (pre-test). A hybrid view model is shown by the two models combined by (&); in this case is the Neoclassical & Classical, and Neoclassical & Mendelian models of the gene. The number in brackets [ ] following each model refers to the number of students for that particular model. Words highlighted in blue show the associated description of the students' verbal definition with its description (second column). The interpretation of the students' pictorial definition of a gene is given in the pictorial description (third column).

Historical model of the gene	***Description of concept of gene (Verbal)***	***Description of concept of gene (pictorial)***	***Sample***	
			Verbal definition*	***Pictures***
(1)	**(2)**	**(3)**	**(4)**	**(5)**
Classical [7]	**Structure of genes:** - unit on the chromosome - a point/part of chromosome - a genetic information on chromosome - a carrier - a genetic material **Function of gene:** - passive transmission - trait determination	**Gene is drawn as:** - a point on a chromosome - a segment on chromosome	*Gene is **a carrier** of the living-beings, which **specifies a trait** and **transmitted** from parents to offspring* ***(Vani/Pre-test)*** *Gene is a **genetic material** owned by all living-beings. Each gene will **determine a specific trait**. (**gene: a carrier** for specific character). For example, gene aa (for) albinism* ***(Vira/Pre-test).***	 *Gene is a segment (a black band) on a chromosome* ***(Vira/Pre-test)***
Biochemical-classical [1]	**Structure of genes:** - a genetic material (chromosome/DNA) **Function of gene:** - trait determination	**Gene is drawn as:** - a segment on chromosome	*Gene is **a genetic material** which has a function **to encode a trait** of an organism or an individual. The genetic material **could be DNA and chromosome** (**Hana/Pre-test)***	 *Gene is a segment (a band) on a chromosome, symbolised by alphabet* ***(Hana/Pre-test)***

Neoclassical & Classical [12]	**Structure of genes:** - a trait - a unit of inheritance - a point/part of chromosome - a sequence of DNA - a sequence of DNA contains trait/genetic information - a genetic code - a carrier - a molecular substance - a genetic material **Function of gene:** - active/passive transmission - trait determination - to generate genetic variation	**Gene is drawn as:** - a sequence of DNA on a segment of chromosome - a segment of chromosome that made up of DNA - a point of DNA on a chromosome - a trait that made up of DNA on a chromosome	*Gene is **a complete sequence of DNA** located inside the chromosome. It serves **to carry genetic information that encodes a specific trait**. Genes reside on the specific locus of a chromosome. Gene could also be the DNA sequence, which is transcribed **to instruct specific characteristic of the organism**.* **(Bona/Pre-test)** *Gene is a unit which has **a function to transmit character** from an ancestor (parental cell), both from paternal and maternal, to the offspring.* **(Omar/Pre-test)**	 Gene is a molecule of DNA on a segment of chromosome **(Bona/Pre-test)**  Gene is a segment of chromosome containing DNA **(Omar/Pre-test)**
Neoclassical & Mendelian [1]	**Structure of genes:** - a trait bearing genetic material - a sequence of DNA **Function of gene:** - to store an encrypted trait	**Gene is drawn as:** - a sequence of DNA	*Gene is genetic material **which carries** a trait which will be decoded through transcription and translation or is **an encrypted sequence of DNA** **(Karin/Pre-test)***	 Gene is an order of nucleotide bases of DNA double helix **(Karin/Pre-test)**

**Verbal definitions were the English translation of the original verbal definition on the pre-test*

A simultaneous examination of the common classical model of gene held by most students of this cohort was confirmed by the analysis of their historical model of a gene using the designated procedure described on section 6.3.3. The result showed that Indonesian students' (IND-2, n=21) model of the gene fell into four categories: classical model, biochemical-classical model, a hybrid of neoclassical and Mendelian model, and a hybrid of neoclassical and classical model (Table 6.5).

Seven (out of 21) students adopted the classical model of the gene. As suggested by its name, this model defined the gene as a unit of inheritance located on the chromosome and/or as the indivisible particle of segment of chromosome (Portin, 1993; Gericke and Hargberg, 2007). Similar representation of a gene was also shown by a student, Hana, who have the biochemical-classical view of the gene. However, she defined the unit of inheritance is both DNA and chromosome. The integration of DNA into her model of the gene made her model categorised as biochemical model of the gene as suggested by Gericke and Hargberg (2007) and Smith and Adkison (2010).

The majority of IND-2 students (57%) held the hybrid of Neoclassical & Classical model of the gene (Table 6.7). In this view, students had the idea of gene as a segment of DNA which identified on their verbal definition of the gene, or on their pictorial representation. The classification for having a hybrid conception of gene was because they identified function of gene as on the classical view, such either as transmitting particle or phenotypic trait determiner (Agorram et al., 2010). By so doing, they combine the view of molecular genetic substance with the classical function of the gene. The difference of this model with a hybrid of Neoclassical & Mendelian model is on the identification of chromosome as the storage of traits or unit of inheritance. The fact that the hybrid models of gene are dominated the students' concept of gene showed that students had partial understanding to the molecular concept of the gene, which was similar to the findings on a study conducted by (Lewis, Leach and Wood-Robinson, 2000a; Lewis and Kattmann, 2004) about the secondary school students' idea of gene in the United Kingdom. The hybrid model which was dominated by Neoclassical & Classical model also justified the dominance of classical model of the gene for this IND-2 cohort.

6.5.2. Misrepresentation of structure of chromosome, DNA, gene, and their relationship

The investigation of students' concept of gene also revealed other misconceptions related to the students' verbal or pictorial representation of the gene. Those findings are presented below.

1. *Incorrect representation of structure of chromosomes or structure of DNA*

Students' misconceptions to the structure of chromosomes was identified from the incorrect use of the related terms or incorrect image representation of the term. In this case, two genetics textbooks served as the source of correct responses.

a) Misunderstandings to the structure of chromosome

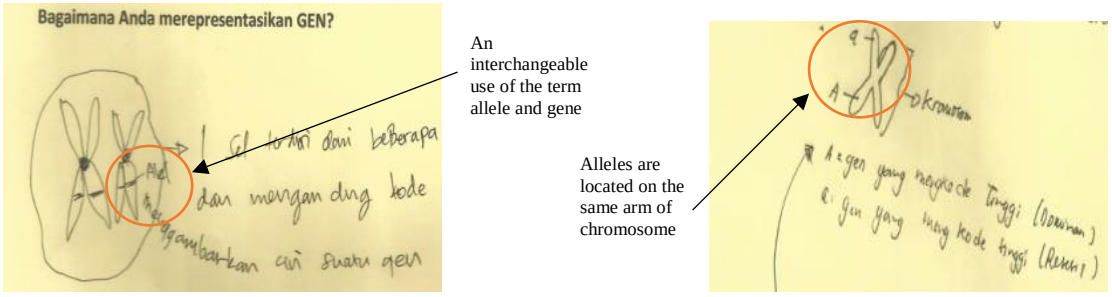


Figure 6. 7 Pictorial representations of gene showing misunderstandings of IND-2 students to the structure of chromosome. *(a) Roni's misrepresentation of gene. He described locus of chromosome as alleles which represented a character of a gene, (b) Gandhes' misrepresentation of sister chromatids structure which showed as labelling different alleles on the same arm of chromosome*

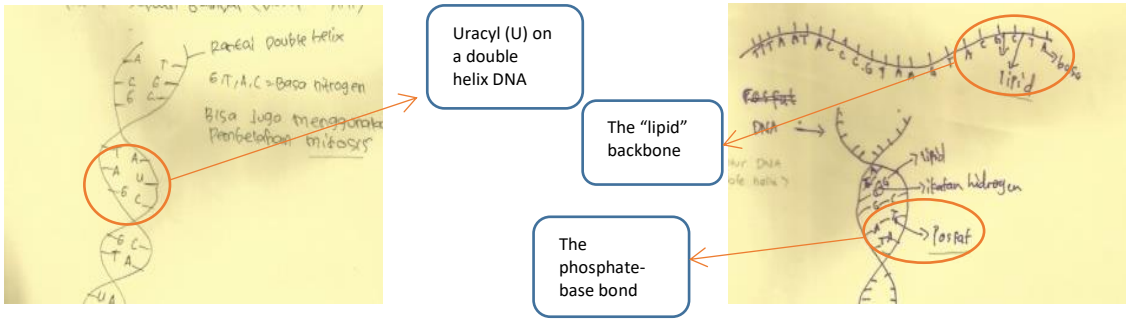
In his pictorial definition, Roni included the statement of "One cell consists of several chromosomes and contains [genetic] code. An allele (here, he refers to a segment of a chromosome) represents a character of a gene)" (Roni/pre-test definition of gene/21 December 2016). His idea of allele is different from the commonly accepted definition of an allele as the alternative forms of a single gene (Klug *et al.*, 2016; Hartl and Jones, 2005; Hartl and Jones, 2005). His idea of a character of a gene matches more with the definition of phenotype as the "physical expression of a trait" (Klug *et al.*, 2016). His pictorial representation suggested that he adopted the term allele and gene interchangeably. A confusion of allele and gene is identified as a common problem in classical genetics view. The reason for this is because the classical genetics emphasise more on the transmission process. A "gene" is defined based on it occupies a locus on a

chromosome, and it contains trait, which in this case, similar to the concept of allele (Flodin, 2009).

In Gandhes's case, she drew different alleles (A and a) of a single gene on a chromosome. Her representation suggested that she had an incorrect understanding of the structure of sister chromatids. A duplicated structured of chromosome (as in her picture), composed of two chromatids, which is a replica to each other (sister chromatids) (Klug *et al.*, 2016), for which they share the same alleles (AA or aa). The "A/a" representation on a single chromosome is possible when genetic recombination (crossing over) occurred; however, she did not explain the concept of alleles within that platform on her picture.

b) Misunderstandings of the structure of DNA

Both Ika and Karin experienced a misunderstanding of the structure of DNA. Ika wrote Uracyl (U) as one of the bases that constituting a double helix DNA, while it should be a member of nitrogen bases that constitute RNA (Hartl and Jones, 2005). As she used both Thymine (T) and Uracyl (U) as a complement base for Adenine (A) on a structure of DNA, she highly likely has a problem in differentiating complementary base pair on a double helix structure (A-T) with the complementary RNA sequence of a transcription (A-U).



(a) (b)

Figure 6. 8 Pictorial representations of gene showing misunderstandings of IND-2 students to the structure of chromosome. *(a) Ika's misrepresentation was complementary A-U on DNA. (b) Karin' misrepresentation was that lipid instead of phosphate constituted the DNA backbone, and phosphate-base bound bridging the DNA backbone and bases*

Karin incorrectly referred to the backbone of DNA structure to the "lipid backbone" and identified phosphate as the structure that bond to the nitrogen bases. The accepted model of double helix DNA explained by (Klug *et al*, 2016, p.280) showed that double helix structure model proposed by Watson and Crick in 1953 is composed

of "sugar-phosphate backbone" with sugar made a glycosidic bond to nitrogen base. This problem may arise because the double helix DNA model commonly focuses on the complementary bases and has less emphasis on the backbone structure.

2. *A misunderstanding of principle of Mendelian inheritance*

A misunderstanding to Mendelian inheritance principle was shown by two students. These participants' ideas are reflected in their verbal definition of gene:

> "*… if we know someone's gene, we can determine that the trait, for example, curly hair, is inherited from its parents, either father or mother must have the curly hair. The curly hair-offspring has inherited it from its parents …"* (Ika/pre-test/21 December 2016)

> "*… in which certain traits will be passed down from parents/ancestor to the descendants/offspring so that the descendant will have the same trait as the ancestor*." (Yeyen/pre-test/21 December 2016).

A dominant view of Mendelian inheritance influenced student thinking that all characters (traits) shown by parents are transmitted following the dominant/recessive transmission patterns. A character that classified as quantitative trait, such as hair shape (curly hair), which is determined by more than one gene is transmitted following Mendelian inheritance pattern. (Mills Shaw *et al*, 2008) reported that this idea had dominated high school (equal to sixth-form-college) students in the USA, and categorised it as one of the misconceptions of genetics. Students lack the sense of the involvement of multiple genes and the environment factors to determine an observable character. This idea could eventually lead to the genetic determinism of a gene (Castéra *et al*, 2008).

3. *Misrepresentation of "DNA inside the chromosome"*

Another misconception found was related to the description of location of a gene. Students used the term "inside" the chromosome, or "inside" the DNA to describe it. Below are quotations from students' definition of gene showing the use of that term (word in bold used to emphasise the term):

1) "*… gene is located **inside** the chromosome"* (Azmi/pre-test/21 December 2016),
2) *"… gene is located **inside** the chromosome, **inside** the DNA"* (Aliya/pre-test/21 December 2016),
3) "*… heredity particle is located **inside** the DNA*" (Sammy, pre-test/21 December 2016),

4) "… *DNA* ***inside*** *the chromosome contains gen*" (Faiza, pre-test/21 December 2016),

5) "….***inside*** *the gene there is DNA double helix*" (Raras, pre-test/21 December 2016),

6) "… ***Inside*** *a gene is a sequence of DNA*." (Laila, pre-test/21 December 2016),

7) "… *Gene is a complete sequence of DNA located* ***inside*** *the chromosome;…*" (Bona, Pre-test/21 December 2016)

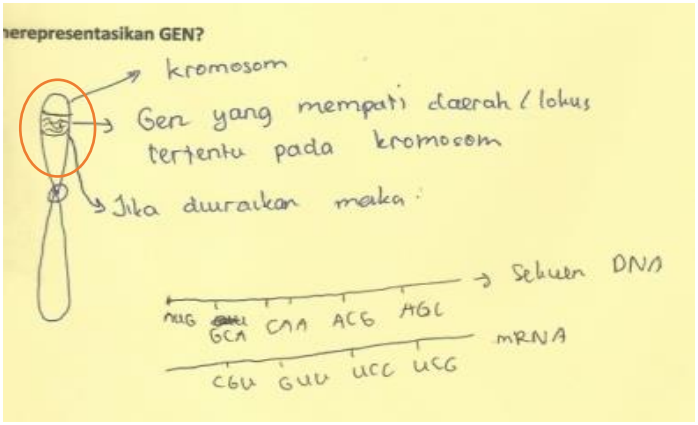


Figure 6. 9 Bona's representation of gene: a sequence of DNA located inside a specific segment on a chromosome. *Gene occupies a specific location on a chromosome. Only on that specific locus, a segment of DNA is present.*

The use of the term "inside" indicated that students misrepresented the relationship between chromosome, DNA, and the gene. Students who stated that gene or DNA is located 'inside the chromosome' (e.g. Bona) has the incorrect image representation of DNA/chromosome as shown on Figure 6.9, suggesting that locus of the chromosome is a holder for a gene (a specific segment of DNA). This representation was incorrect scientifically. A chromosome should be represented as one continuous strand of DNA, such as explained on "…*in eukaryotes,* [a chromosome is] *a DNA molecule complexed with RNA and proteins to form a threadlike structure containing genetic information arranged in a linear sequence*" (Klug *et al*, 2016, p.844).

Parallel to false representation above, the use of term 'inside' in describing relation between two structures, for example "gene is located 'inside' the DNA" (e.g. Aliya), or 'DNA is located inside the gene' (e.g. Jono) may indicate students' have the mistaken idea of their relation. The incorrect perception about the relation between gene and DNA also comes up in discussion when students read the booklet on Neoclassical section. This was triggered by the confusion of which views is correct, "*gene is located 'inside' the DNA or the opposite condition*" (Observation notes/R4/21 December 2016).

Students' misrepresentation of the relationship between gene and DNA is related to an incomplete understanding of the structure of DNA and gene. A gene in the molecular genetic view is defined as a discreet segment of DNA (Portin and Wilkins, 2017). To represent the idea, a pictorial representation is presented as on Figure 6.10. The incorrect interpretation to the picture produces the idea that seeing the gene is located 'inside' a DNA molecule (Figure 6.10.b) or DNA (as a sequence of nucleotides) is located 'inside' a gene (Figure 6.10.c). The former incorrect idea may be perpetuated by the incorrect interpretation of "gene occupies a locus of chromosome" which represented a locus of a chromosome as a container for a gene (Nusantari, 2002). The latter incorrect idea may lead to another wrong idea, such as a complex molecule of DNA as nucleotide (see section 4.8.5).

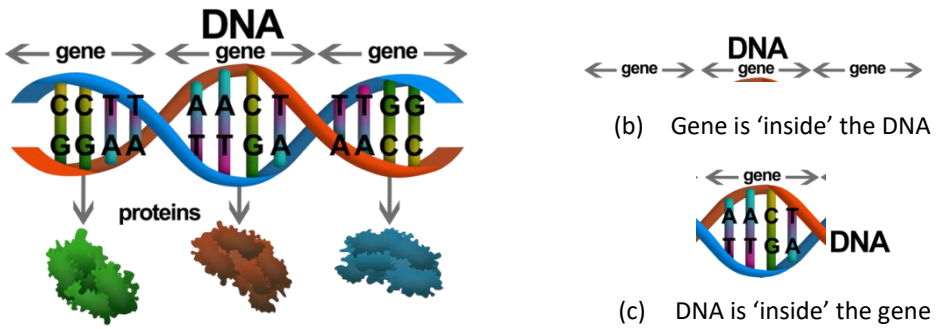


Figure 6. 10 A typical representation of relation between DNA and gene and the possible misinterpretation from understanding the picture. *(a)The correct interpretation: gene is a certain segment of DNA on a DNA double helix. Possible incorrect interpretation based on IND-2 students' view: (b) 'Gene is (located) inside the DNA (double helix molecule)'; (c) 'DNA is (located) inside the gene' (iage source: kissclipart, n.d)*

6.5.3. Impact of the gene concept booklet: IND-2

The effectiveness of the educational booklet in promoting revision of misconception is evaluated through the changes on students' definition or representation of gene through testing and interview, and through the perception of students on how the booklet influence their changes of concept.

Students' changes idea of gene was assessed from comparing their definition of gene before and after teaching session with the booklet. The redefinition of a gene involved both verbal and pictorial explanation. The post-learning test was used to identify any changes to the individual student's conception of gene. A comparison

between students' concepts of a gene before and after the learning session with the education booklet is presented in table 6.8, 6.9, and 6.10. The three tables focus on showing the idea of gene by looking at its structure, function and pictorial representation, respectively.

Table 6. 8 Indonesian students' idea of the structure of the gene based on verbal definition (IND-2 case, n=21).

The number of students who shared their respective ideas concerning the gene before and after reading the educational booklet is shown in the pre-test and post-test columns, respectively. The responses are not mutually exclusive, one individual may hold more than one idea concerning the gene. The numbers in bold (grey shading) shows the total number for each thematic idea (coding) under the same category.

Categories of gene structure	Coding	Number of students	
		Pre-Test	Post-Test
Symbolic (abstract)	**a phenotypic character/trait**	**1**	**1**
	a trait	1	1
	a unit of inheritance	**4**	**1**
	a carrier	2	-
	a unit of inheritance	2	1
Cellular	**a part of chromosome**	**4**	**1**
	a trait-bearing-unit on chromosome	1	1
	a segment of chromosome	3	-
	a chromosome as a unit of inheritance	**1**	**1**
	an inheritance on the chromosome	1	1
Cellular/ Molecular	**an inheritance on the DNA/chromosome**	**2**	**1**
	a trait on the DNA/chromosome	-	1
	a unit of inheritance on the chromosome/DNA	2	-
	a genetic information	**2**	**1**
	a unit of genetic information on a chromosome	1	-
	a sequence of genetic information on DNA	1	1
	a genetic material	**3**	**2**
	a genetic material	1	-
	a genetic material on the chromosome	-	1
	a genetic material (DNA/chromosome)	1	-
	a genetic material (DNA)	1	1
Molecular	**a molecular substance**	**1**	**1**
	a molecular substance	1	-
	a long sequence of nitrogen bases	-	1
	a DNA unit of inheritance	**2**	**-**
	a unit of inheritance on the DNA	1	-
	a DNA-bearing trait	1	-
	a molecule of DNA	**-**	**1**
	a molecule of DNA on a chromosome	-	1
	a sequence of DNA	**4**	**3**
	a sequence of DNA	2	2

	a trait-bearing segment of DNA on the chromosome	1	-
	a complete sequence of DNA on a segment of chromosome	1	-
	a sequence of DNA that serve as a template	-	1
	a transcriptional unit	**-**	**9**
	a transcriptional unit	-	7
	a transcriptional unit (min. 100bp)	-	1
	a trait-bearing transcriptional unit	-	1
	a genetic code	**1**	**-**
	a trait-bearing genetic code	1	-
Total ideas		**25**	**22**

Table 6.8 displays various gene concepts, ranging from abstract to the molecular organisation of the structure of gene. By comparing with these with prior concepts, the idea of the gene tended to be based more on molecular perspective. There was one concept of a gene which was not seen before learning with the booklet, the concept of a gene as a transcriptional unit of DNA. Here, a gene is defined as "*a segment of DNA between the sites of initiation and termination of transcription by RNA polymerase*" (King, Mulligan and Stansfield, 2013, p.478). The progressive idea of gene is the acknowledgment of intervening sequence (intron) between protein -coding areas (exon). Hence, students adopting this model of a gene, do not see the gene merely as a continuous sequence of DNA that is transcribed to mRNA to code for a polypeptide. They further incorporated the idea that the sequence of DNA has a specific region (coding area) which will be experience the post-transcription process after transcribed to mRNA to code for a polypeptide (Klug *et al*, 2016). This showed that a number of students had a deeper understanding of the molecular construction of a gene.

The redefinition to the concept of the gene as "the transcriptional unit of DNA" for this cohort was also introduced when they worked with another learning resource, The Human Beta Haemoglobin (HBB) Gene Simulation (this material is not presented in this thesis). This resource asked students to demonstrate the stages of gene expression, including the modelling of splicing and the excising of an intron from the mature mRNA transcript. In simulating this process, students were introduced to the idea of a gene as a transcriptional unit. Many students liked this simulation activity which showed that they had readily transitioned to the new conception of a gene, though it did not immediately guarantee that they incorporated this new concept into their own self-concept of a gene.

Table 6.8 shows another trend in reduction of the number of hybrid classical-molecular conceptions of a gene. For example, the ideas visualising a gene as a unit of inheritance on the chromosome/DNA, as a trait-bearing segment of DNA or of the DNA as a unit of inheritance had been reduced to zero. This indicated that students have a greater understanding of the molecular model the gene, separating it from the classical model of the gene.

Table 6. 9 Indonesian students' idea of the function of the gene based on verbal definition (IND-2 case, n=21).

The number of students who shared their respective ideas concerning the gene before and after reading the educational booklet is shown in the pre-test and post-test columns, respectively. The responses are not mutually exclusive, one individual may hold more than one idea concerning the gene. The numbers in bold (grey shading) shows the total number for each thematic idea (coding) under the same category.

Categories of gene function	Coding	Number of students	
		Pre-Test	Post-Test
Trait-related function	**Transmission of trait**	**14**	**9**
	active transmission of trait/genetic information	3	2
	passive transmission of trait/genetic information	11	7
	Trait determination	**9**	**2**
	to specify a trait	9	2
Protein production-related function	**Protein production pathway**	**-**	**7**
	to encodes DNA, to produce RNA and protein	-	1
	to produce enzyme and other products	-	1
	to produce RNA-protein	-	1
	to produce RNA-polypeptide-peptidoglycan	-	1
	to produce protein	-	1
	to produce an enzyme/polypeptide/RNA and protein	-	1
	to produce amino acids/to produce RNA/to produce polypeptides	-	1
Other function	**Non-trait, non-protein function**	**1**	**1**
	generating genetic variation	1	-
	to serve as a template	-	1
No associated function	**No specific function**	**-**	**6**
	No specific function	-	6
Total ideas		**25**	**22**

An improvement to the understanding of the gene model was indicated by the changing way students saw function of a gene (Table 6.9). There were a reducing number of students relating the gene with its phenotypic trait, i.e. seeing the gene as a transmission tool in inheritance and as a trait determiner. Another interesting feature is the increasing number of students who realised the function of gene in producing

molecular products. Lewis, Leach and Wood-Robinson (2000a) and Lewis and Kattmann (2004) showing that one of the problems in conceptualising a molecular gene is the less acknowledgement of the function of a gene to specify a molecular product, polypeptides/protein. Thus, this phenomenon might be an indicator of the value of this educational booklet in promoting learning of the gene concept. However, there are a number of students (6) who did not include the function of a gene in their conceptual model. By observing their response sheet, it seemed that this group of students focused their attention more on revising the structure of a gene.

Table 6. 10 Indonesian students' idea of the gene based on pictorial definition (IND-2 case, n=21).

The number of students who shared their respective ideas concerning the gene before and after reading the educational booklet is shown in the pre-test and post-test columns, respectively. The responses are not mutually exclusive, one individual may hold more than one idea concerning the gene. The numbers in bold (grey shading) shows the total number for each thematic idea (coding) under the same category.

Categories of gene	Coding	Number of students	
		Pre-Test	Post Test
As a part of chromosome	**a dimensionless point on a chromosome**	**3**	**1**
	a point on a chromosome	2	1
	a point on a chromosome in the nucleus of a cell	1	-
	a segment of chromosome	**8**	**1**
	a segment of chromosome	7	1
	a segment of chromosome contains "genetic code"	1	-
	one of a series of segments on chromosome	**-**	**4**
	one of a series of segments of chromosome made up of DNA	-	1
	one bead on "beads on a string"	-	3
As a symbol of reservoir of gene	**a chromosome and double helix DNA**	**1**	**3**
	a chromosome made up of DNA and histone	-	1
	a continuous helical strand contains DNA that construct a chromosome	1	-
	a chromosome, and a segment of double helix DNA	-	1
	a diagram of chromosome-->DNA-->gene	-	1
As a part of DNA on chromosome	**a molecule of DNA inside a chromosome**	**-**	**1**
	one molecule of DNA inside a chromosome	-	1
	a segment of DNA on chromosome	**3**	**4**
	a sequence of DNA on a particular segment of chromosome	2	-
	a segment of DNA on a DNA-constructed chromosome	1	3
	a segment of DNA (5'-3') that makes up a chromosome	-	1
	a point of DNA that makes up a chromosome	**3**	**8**
	a point of DNA on a DNA-constructed chromosome	1	5
	a point of DNA inside the chromosome	1	-
	a genetic information on a DNA-constructed chromosome	1	-
	as DNA that reside along the chromosome	-	2
	a part of DNA in a segment of chromosome	-	1

	a trait that made up of DNA on a chromosome	**2**	**-**
	a trait made up of DNA in a specific segment of chromosome	1	-
	a trait-containing DNA of a chromosome	1	-
As a sequence of DNA	**a sequence (segment) of DNA**	**3**	**3**
	a sequence (segment) of double helix DNA	3	2
	a segment of DNA double helix (5'-3')	-	1
	a transcriptional unit	**-**	**5**
	a transcriptional unit of a chromosome	-	5
As a functional gene	**Product of DNA pathway**	**1**	**2**
	a diagram of central dogma (DNA-->RNA-->protein)	-	1
	a sequence of DNA and a complement sequence of mRNA (transcription)	1	-
	a sequence of DNA with a respective sequence of RNA and of peptides/protein	-	1
Total ideas		**24**	**32**

The progressive definition of a gene also identified the improvement on the elements of their images of gene (Table 6.10). After the learning session, there were fewer students defining a gene as a segment of a chromosome. They revised their concept either by placing the gene as one of a series of segments of a chromosome, or by interrelating chromosome and DNA (as in the drawing of gene as part of DNA that constitute a chromosome). This progression was indicated by increasing number of ideas with respect to the categories of a gene as a part of DNA on a chromosome.

The progress of students' definition of gene was reflected on the changes on their evaluation of the historical model of a gene and a revision of their verbal/pictorial conceptions (see Table 6.10). Students who previously adopted the classical model of gene advanced their model by incorporating the relation between chromosome and the double helix DNA. The acknowledgment of double helix model of DNA which was discovered by Francis and Crick in 1953 marked the neoclassical model of definition of gene (Smith and Adkison, 2010). This also applied to students who previously adopted the biochemical model of gene. Some other students had revised their concept of a gene to include the structure of unit of transcription. This understanding marked the modern concept of the gene (as shown on Table 6.5).

Although some students did not change their model of gene (N/C→N/C), but they improved their idea of gene, by revising their image of gene or by adding supporting concepts that they did not realised before. Include in this change were the addition of specification of molecular function of gene (Omar), a revision to the way DNA condensed to chromosome (Jono and Laila), additional direction of DNA, 5'-3' (Sammy), and the recognition of gene as part of chromosome (Ika). Regards to the

latter, although it seemed to be going back to the classical period, Ika claimed this as her valuable change that she acquired from her learning experience with the booklet, as she stated that:

> *"Em, before* [learning], *I defined gene as an inheritance. Before, I wrote that a gene is located in the chromosome, no,* [I mean] *in the DNA. After the explanation* [class discussion], *I was asked what a gene is, then I suddenly* [realise] *that gene is located in the chromosome. And the location is not changeable. ... After listening to the explanation,* [I said] *"Oh, the gene is located in the chromosome, and the location is fixed". That's the change. ... If previously I had drawn only double helix DNA, but then I drew chromosome as well, so we know where the DNA is..."* (Ika/Interview/24 Dec 2016).

Her excerpt shows that she valued the location of gene on the chromosome as one of her new understandings of the gene. Although she included a drawing of chromosome both on her prior and latest model of the gene (see Table 6.11, column not changes), her intention was completely different. In her previous model, her idea was to show that gene is located in the DNA on the chromosome. It is different with her "new" conception of a gene as it is "located on a locus (segment) of chromosome" which came later.

Students' changes on their conception of gene as depicted on Table 6.11 could be referred back to their learning experience with the gene concept booklet. Here, the process of learning involves two elements, the learning material (the educational booklet) and the instructional activity (the way the booklet is used in the learning process). The two elements work synergistically in creating an effective teaching/learning activity (Kemp, 1977; Gagné *et al*., 2005). Thus, there was a difficulty in evaluating the educational booklet separately from the related teaching activity. Also, students did not always make clear separation of their comments about the media or the activity when they were asked about their learning experience. With a single instructional activity which asked students to evaluate the similarities/differences of their concept of a gene with the model of gene presented on the booklet, the booklet of the gene concept is seen as an integral factor with the activity. In this sense, the evaluation of the booklet of the gene concept referred to the students' evaluation of both booklet and activity.

Table 6. 11 The changes to Indonesian Students (IND2) concept of the gene after learning episode with booklet of the gene concept

The changes on the verbal /pictorial concept of gene were used to determine the change on students' historical model of the gene. The symbol of → indicated the change. The historical model of the gene was stated in abbreviation, with symbol "/" showed the coexistence of two models or more. The models of the gene are (in alphabetical order) B= Biochemical-classical, C= Classical, M = Mendelian, Mo = Modern, N = neoclassical)

Pseudonym	Revision to model of gene	CHANGES on		Not changes
		VERBAL concept	PICTORIAL concept	
Mimi	C → N	a segment of chromosome for transmission → a molecule of DNA	a segment on chromosome → a molecule of DNA (a gene)	-
Azmi	C → N/C	-	a segment on chromosome → a point of DNA; DNA makes up a chromosome	gene is involved in transmission
Roni	C → N/C	a code → a code on a segment of DNA	a segment on chromosome → a sequence of DNA; DNA makes up a chromosome	gene is involved in transmission
Vani	C → N/C	a carrier → a trait on DNA	a point on chromosome → a point on DNA; DNA makes up a chromosome	gene is involved in transmission
Gandhes	C → Mo	a segment of chromosome that involve in transmission → a transcriptional unit	a segment on chromosome → a point on DNA; DNA makes up a chromosome	-
Vira	C → Mo	a genetic material or a carrier that specifies a trait → a transcriptional unit to produce polypeptides	a segment on chromosome → a transcriptional unit	-
Nonik	C → Mo/C	a genetic information on chromosome involved in transmission → a transcriptional unit to produce a protein	a segment on chromosome → a sequence of DNA on a chromosome that produce protein	gene is involved in specifying trait
Hana	B → N/C	a genetic material (chromosome/DNA) → a genetic material (DNA)	a segment on chromosome → one of a series of segment on a chromosome that made up of DNA	gene is involved in the transmission or determination of trait
Karin	N/M → Mo	a sequence of DNA to store a trait → a transcriptional unit to produce protein	a segment of DNA --> a transcriptional unit	-
Dina	N/C → N	DNA that contain genetic information and involved in a transmission → a sequence of DNA	A diagram of a gene as a genetic information located on chromosome/DNA which involved in transmission → a diagram of a gene that is located on a chromosome as a segment of DNA	-

Table 6.9 continued...

Pseudonym	Model of gene	Changes on …		Not changes
		VERBAL concept	PICTORIAL concept	
Ika	N/C → N/C	a unit of inheritance, DNA → a unit of inheritance on chromosome	(adding a picture of beads on a string)	gene is involved in transmission; (drawing) a chromosome and a segment of DNA
Jono	N/C → N/C	a trait → a genetic material on chromosome	a segment on chromosome, a segment of DNA → DNA makes up a chromosome	Gene is involved in transmission
Laila	N/C → N/C	gene is involved in a determination of trait → gene acts as a template	a segment of DNA genes (DNA) on a segment on chromosome → genes (DNA) reside on chromosome	a sequence of DNA
Omar	N/C → N/C	a unit on chromosome for transmission → a sequence of DNA to specify polypeptide/enzyme	-	(drawing) a segment on chromosome contains DNA
Sammy	N/C → N/C	unit on DNA → a trait	5'→3' direction on a segment of DNA	transmission; (drawing) a point on chromosome and a segment of DNA
Yeyen	N/C → N/C	a trait for transmission → an information on DNA/chromosome	a trait on DNA → genes (DNA) that make up a chromosome	(drawing) of a chromosome that made up of DNA
Aliya	N/C → Mo	a unit of inheritance on DNA that involved in transmission → a transcriptional unit to code for protein	a segment of DNA on chromosome → a point on DNA; DNA makes up a chromosome	-
Raras	N/C → Mo	a unit on a chromosome or a molecular substance that involved in trait transmission and determination → a transcriptional unit	gene contains DNA → gene inside the DNA; a transcriptional unit	-
Unika	N/C → Mo	an inheritance on chromosome that involved in transmission → a transcriptional unit	a central dogma diagram	(drawing) a segment of chromosome, a segment of DNA
Faiza	N/C → Mo/C	a segment of DNA → a transcriptional unit	beads on a string and transcriptional unit	the molecular substances contain trait, and is involved in transmission
Bona	N/C → M/C/Mo	a sequence of DNA involved in transmission → a unit of heredity involved in transmission; a transcriptional unit to produce an enzyme/other products	a segment of DNA genes (DNA) on a segment on chromosome → a chromosome made up of DNA; beads on a string; a transcriptional unit	-

6.5.4. IND-2 Students' perception of the gene concept booklet

There were two things that made students appreciate the booklet of the gene concept. For the Indonesian students, the booklet is the first material that they had seen which specifically discusses the concept of the gene. Second, the booklet focuses on presenting the progressing concept of the gene in a historical order. All students agreed that these two features made them re-think their understanding of the gene when they read the booklet. They also learned to think about having a solid self-definition of that important concept. Although the gene is a central concept in genetics, they have never been challenged to discuss the concept on its own, thus they less value the concept. Bona clearly captured this thought in her interview below:

I : Well, now we will talk about your experience learning with resource 4 [the booklet of the gene concept]. What did you get out of the learning process?

Bona : Oh, from our last meeting, hmm, do you mean what information I got? First, [I realised] the gene concept is not as simple as I thought. I discussed it with my friend, "how come this information is not delivered to us [for all this time]*?" well, yah, it should be step-by-step. This is not a kind of information I will receive in secondary (age 13-15) or high school (age 16-18). But, there should not be any information on the* [school] *textbook stating that this definition of gene is, hmm, a standard one. We know that this is standard because we found it in any book. Well, it relates to the Mendelian law etc. If we commonly found* [those idea] *it means we were dictated that it is the correct definition and we have to follow it. That's way our understanding of a gene all this time is the inheritable unit of heredity (laugh). And we were never told that, hmm, I wish that the book explained that there are many definitions of gene made by scientists, and we just simplified them. So, we will not stop just in that* [standard] *definition of gene. When I got the [various] concepts of gene,* [I realise] *there are many definition of gene (laugh). For all this time, I studied genetics and disregard the term "gene". I thought, it just a term, because genetics is a subject that studies about gene. So, it just a small stuff, the gene, chromosome. I just read it once and see that "oh that it's definition". I focused more on the function of genetics, like mechanism in transcription, etc. And I totally forget about the* [concept of] *a gene. When I now know, gene is defined based on era of Mendelian, Classical, Biochemical, Biomolecular, HGP, like that. So, that's a lot of definition* [of gene]. *And it is clear, the definition of gene, not abstract anymore (laugh). So, what we defined* [of gene] *for all these years* [are] *classical (laugh). And I adopted that term (laugh)*

(Bona/Interview/22 December 2019)

The single focus of the booklet, the concept of the gene, and its historical order presentation had helped students in revisiting the concept and connecting ideas that they have never done before. Although it later showed that students' new conception was not always correct, an insight into challenging the self-concept of gene has brought a

positive environment for the learning process. Statements from Karin and Sammy provide further understanding of this situation.

> *"Oh, I used to study genetics, like studying the process inside a cell, I never connected that with what I learned on other subjects. So, I just stuck on ... like, if for example, a gene is a genetic material that contains DNA which then transcribed and translated into RNA which then produces a protein. Well, I learned at high school (age 16-18, red) that eukaryotic, uhm… prokaryotic is well, like virus, only have RNA. But, I never connected this knowledge with the definition of a gene. After last meeting (evaluating the booklet of the gene, red), I just realised that the gene could be defined like this…the genetic material in living things, the prokaryotic, is RNA, but that's the RNA that could replicate!" (Karin/Interview-3/24 December 2019)*

> *"Oh, I thought… it's* [booklet] *good. Because there are* [definition of gene of many] *scientists apart from Mendel that I just never read before…" (Sammy/Interview-3/23 December 2019)*

Although Karin showed a misconception in the genetic material of prokaryotic organism, which she claimed as RNA, she took a first step in connecting knowledge across the subject (based on her claim) to define a gene. Making this connection is a sign of stage in achieving an understanding, which is the ultimate purpose of learning, particularly for higher education (Newton, 2011). Because of the single focus of the booklet on revising the gene concept, it also benefitted students to know the related event and research in conceptualising a particular model of gene. What Sammy brought about was the fact that many students only thought they were introduced to Mendel's concept of gene (see an excerpt from Bona's interview for another reference). This happened because genetics usually starts with the definition of a gene which lead students to the next topic, commonly Mendelian concept of classical genetics. This "historical approach of teaching genetics" is the most adopted method in presenting genetics (Griffiths and Mayer-Smith, 2000). Many university and high school (age 16-18) textbooks of Biology which cover the concept of genetics adopt this approach (e.g. (Raven and Johnson, 2002), and Biology textbook by Campbell (2000) which was cited in their initial interview (interview 1) as the only textbook reference for studying genetics for this particular group of student. The problem arises not because of the approach, but more because there is a less chance to redefine the gene from a classical into the molecular model. Students were given the molecular definition of a gene, but the definition did not become the centre of attention, as students jump over to the topics that they thought more important (see an excerpt from Bona's interview for illustration

of this). In this case, booklet gave students an opportunity to revisit their idea of gene by focusing only on the historical progress definition of a gene over time.

Furthermore, a specific presentation of a booklet which focuses on the progressive conception of a gene has swiftly mediated students to build their understanding of the gene concept. A quotation from students' interview showed how they appreciated the historical order presentation of the gene that helped them to redefine their concept of the gene.

> *"The advantage is that it is presented step-by-step, era by era, by doing so, it could change someone's conception. That's the benefit (Nonik/Interview3/23 December 2019)*

> *"Last time, the resources* [booklet] *presented an order of the concept of the gene, started with Mendel. So, we can understand how to understand the gene. In other words, well, we study from the beginning to the modern conception, hmm, in order, so eventually we got the concept of the gene by ourselves." (Dina/Interview3/22 December 2019)*

> *What I like is… when I was given the booklet, from this era to that era… so, it showed the updating concept, a new definition of gene. … That's the most favourite part. (Laila/Interview3/22 December 2019)*

> *I know more about the beginning of [conceptualisation] of gene. From imperfect definition of gene in to the place where the gene is located. And the original idea of the gene" (Vani/Interview3/23 December 2019)*

The redefinition of the gene was also triggered by the fact that the model of a gene put a range of years. Students were challenged to change their concept by looking at the year of each model. Many students thought that this presentation worked well and were surprised that they held such an old definition of a gene (as quoted below):

> *"Yap, so… I just realised that my conception of gene is very old fashion. I even forget what year it is. So, my idea was so… so old. That's it." (Aliya/Interview3/22 December 2019)*

> *"It is useful, because I can make a comparison. Like when I look at the first and the second sheet. Well, it just more or less the same with what I know when I was in secondary* [age 13-15] *or high school* [age 16-18], *including the crossing. So, I could say, I was on that group (middle schoolers, red)" (Omar/Interview3/22December 2019)*

> *"There was a difficulty to describe the gene in the previous era. A limitation. Well, it seemed that the way I define the gene is the same with them. They called the gene the unit of heredity. I adopted that definition until now. Well, it is like, my idea just till that time, and I did not re-examine thing." (Raras/Interview3/22 December 2019)*

In general, there were two important roles of booklet for changing the IND2 students' conception of the gene. First, the focus of a booklet on a gene concept focuses students to observe how the concepts of a gene were evolving as the findings from the advancing research in genetics contributed to the model of gene. Second, the historical presentation of the concept of the gene instigated students to re-evaluate their concept of gene. In this case, the historical model presented on the booklet acted as scaffolding to the idea of the gene.

Students' changes in the conception of the gene as depicted on Table 6.9 further suggested us to classify the changes into two groups: (1) the perspective changes of the gene, and (2) the structural changes of the gene. The first changes involve the radical redefinition of what they considered as gene, whilst the second gave a subtler concept to their definition of the gene, involving the revision to the concept of the gene, without having a radically change on the way they defined the gene.

Two students consistently showed the radical changes to the idea of a gene, Vira and Bona. Vira first conceptualised a gene as a segment on chromosome (classical view). She then changed her concept of gene into a modern molecular view. She realised that her concept was old-fashioned and want to change. She understood the modern molecular concept through her learning experience with booklet of the gene.

Interviewer: Where did you get your (old) images of gene?
Vira: From any reading materials. Because most of them said so, that is what I store in my memory.
Interviewer: After you learn the model of genes, did you have any change in your concept (of gene)?
Vira: I want to change. Well, at least into the molecular era. That's it, the one which explains DNA is a structure of promoter, exon, intron, and UTRs.
Interviewer: So, if you are asked to redefine your concept of gene, what would that be?
Vira: Well, that would be that. Gene is a sequence of DNA comprised of a promoter, exons, introns, and UTR which encode amino acid. Period.
Interviewer: Why do you want to change into this concept?
Vira: Well, because … I don't know (laugh). At least I have a progressing concept, not in the Mendelian anymore, but advancing
Interviewer What is wrong with having Mendelian concept of gene?
Vira: I think it's too old (laugh)
Interviewer: What makes you want to alter your concept?
Vira: Em... what? I think .. so, that I would change
Interviewer I: And why do you think do you want to change?
Vira: Em.. Because I think my old concept is too … general. So, it will not be fit to adopt that today.

(Vira/Interview3/24 December 2019)

In contrast to the first case, Bona had reconceptualised the various definition of gene which she learned from reading the booklet. Later, she offered to give several definitions of gene. She realised that there are some limitations in explaining the gene based on a certain model. For example, she stated that it will be difficult to explain the neoclassical model of gene to her parents and to the public in general. She was first annoyed by the fact that she never paid more attention to definition of a gene and satisfied with her old definition of gene (as a unit of heredity). However, instead of coming with a certain concept of the gene, she changed her view in describing the gene and came with the multi-definition concept of the gene. She wrote her view on her post-test sheet and it is confirmed with her statement in the interview below.

Interviewer: After learning with booklet, what is you concept of gene?

Bona : Ah... (laugh) it is a bit complicated to explain. So, I will explain… uhm well, then if I were asked "what is gene"? then I will reply which definition of gene should I explain? (laugh)

Interviewer : (laugh) Okay then, which definition of gene do you want to explain?

Bona : ... to my understanding, this [definition of the gene] *would be fit. Per episode, So, if it is classical,* [I will] *give the main characteristics, like there were certain dogma. Then, maybe Mendelian [model]. Hmm… If somebody ask what a gene is, I would probably go with "there are many definitions of gene. Which one do you want me to explain, Mendelian, Classical or others? Or if they want the current model, I will explain gene is a sequence of DNA consists of several components, promoter, coding area, UTRs, etc. Or if they want the simple thing, I will use an illustration of gene as beads on a string, that's it. That's what I understand.*

(Bona/Interview3/22December 2019)

In general, it is clear that for this Indonesian cohort, the educational booklet of the gene concept had helped these students to formulate their ideas of the gene and to change their understanding accordingly. The changes could take form of having a different model of gene, or a revision to the relationship between chromosome and DNA sequence. Although students were mostly engaged with the learning process using the booklet, students who did not like reading seemed to benefit less using the booklet. In addition, working with verbal and pictorial presentation of a gene concept not only provided an understanding of the way students' ideas of a gene change, but also provided an opportunity to explore other misconceptions.

6.6. Evaluation of the impact of the gene concept booklet on students' understanding: UK

An equivalent evaluation of the benefit of the education the gene concept booklet was conducted with UK students. Students' initial ideas of a gene served as the basis knowledge of gene to depict the changes of the idea after reading the booklet. The differences of the existing understandings of gene with their counterpart study in IND-2 case served as crucial information to understand in a broader context of the way booklet assisted students to reconceptualise their idea of a gene.

6.6.1. UK Students' (UK) existing conception of gene

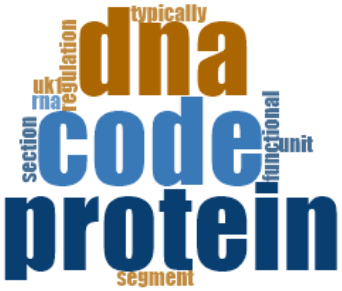
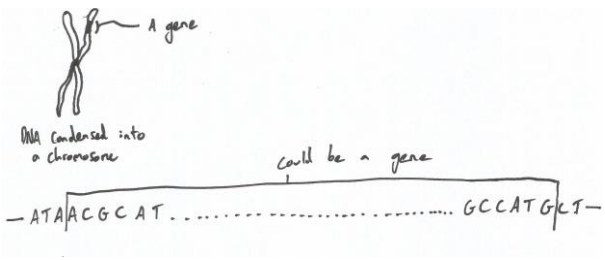
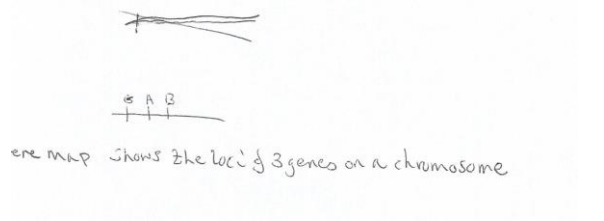


Figure 6. 11 Terms used by students in UK case to describe gene before learning with educational booklet (n=2). *The greater frequency is shown by the bigger size of words. The word "gene" had been removed for it was the word in question. Also, conjunctions and other determiners have been removed*.

The initial idea of a gene for the two students in this group was the segment of DNA that code for a protein. This idea was immediately observed on the word cloud analysis (NVIVO12) (Fig. 6.11) which showed the three key-terms "DNA, code and protein" associated to the molecular concept of gene as a contiguous stretch of DNA that is transcribed as one unit into messenger RNA, coding for a single polypeptide (Portin, 1993). This kind of understanding could be classified as holding the neoclassical model of the gene (Portin, 1993; Gericke and Hargberg, 2007; Smith and Adkison, 2010). However, one UK student also represented a gene as a locus of chromosome (see Table 6.12), showing a combined view of a gene, incorporating the molecular model (Neoclassical) with classical genetics. Therefore, this student held the hybrid concept of Neoclassical-Classical model of gene. Moreover, no identified misconceptions regarding the terms or supporting concepts to their model of gene were observed.

Table 6. 12 Various historical models and conceptions of gene from students in the UK case based on their individual verbal and pictorial definition of gene (n=2)

The table showed the historical model of the gene constructed from students' verbal and pictorial conceptions of gene. The questions are given just before students use educational booklet (pre-test). A hybrid view model is shown by the two models combined by (&); in this case is the Neoclassical & Classical model of the gene. The number in brackets [ ] following the model of the gene refers to the number of students for particular model. Word highlighted in blue showed the associated description of samples' verbal definition to its description (second column). The interpretation of the samples' pictorial definition of gene is given on the pictorial description (third column).

Historical model of the gene	***Description of concept of gene (Verbal)***	***Description of concept of gene (pictorial)***	***Sample***	
			Verbal definition*	***Pictures***
Neoclassical [1]	**Structure of genes:** - a segment of DNA **Function of gene:** - to code for a functional unit (protein)	**Gene is drawn as:** - a segment on a DNA-constructed chromosome - a sequence of DNA	*A gene is* ***a section of DNA*** *that* ***codes for 1 functional unit****, typically a protein* ***(Noah/Pre-test)***	 **(Noah/pre-test)**
Neoclassical & Classical [1]	**Structure of genes:** - a segment of DNA **Function of gene:** - to code for protein/RNA/regulator protein	**Gene is drawn as:** - gene is a segment on a chromosome (locus)	***A segment of DNA*** *that* ***code for protein or RNA*** *or the regulation of other genes* ***(Charles/Pre-test)***	 **(Charles/pre-test)**

6.6.2. Impact of the gene concept booklet: UK

The impact of using the educational booklet on this particular student cohort was evaluated by identifying any changes to their idea of gene after the learning session. Data from students' test, observation and interview were used to conceptualise the findings. The group of UK students involved in this study is very limited (n=2). Despite this is quite a small sample, the evaluation of booklet with this group shows some useful information.

Table 6.15 showed the changes of the structure concept of the gene. Although structurally students described the gene based on a molecular view, but there was additional detail to their structure of gene. Both students initially defined a gene as a segment of DNA, but then changed this into describing the gene as specific sequences of DNA of which some nucleotide sequences may overlap with other genes. One student, Charles, detailed his definition of a gene into a specific segment of DNA that specified regulatory and coding region of the gene.

To analyse any changes in students' understanding, the concept of a gene was investigated in three different ways: the structure of gene (verbally), the function of gene (verbally) and the pictorial representation of what they defined as a gene (see Tables 6.13, 6.14, and 6.15 respectively).

Table 6. 13 UK students' idea of the structure of the gene based on verbal definition (UK case, n=2).

The number of students who shared their respective ideas concerning the gene before and after reading the educational booklet is shown in the pre-test and post-test columns, respectively. The responses are not mutually exclusive, one individual may hold more than one idea concerning the gene. The numbers in bold (grey shading) shows the total number for each thematic idea (coding) under the same category.

Categories of gene structure	Coding	Number of students	
		Pre-Test	Post-Test
Molecular	**a sequence of DNA**	**1**	**1**
	a segment of DNA	2	1
	a transcriptional unit	**-**	**1**
	a transcription unit	-	1
	a specific segment of DNA on overlapping genes	**-**	**1**
	a segment of DNA on overlapping genes	1	1
Total ideas		**2**	**3**

Table 6. 14 UK students' ideas of the function of the gene based on verbal definitions (UK case, n=2).

The number of students who shared their respective ideas concerning the gene before and after reading the educational booklet is shown in the pre-test and post-test columns, respectively. The responses are not mutually exclusive, one individual may hold more than one idea concerning the gene. The numbers in bold (grey shading) shows the total number for each thematic idea (coding) under the same category.

Categories of gene function	Coding	Number of students	
		Pre-Test	Post Test
Trait-related function	**Transmission**	**-**	**1**
	to transmit a phenotype (active)	-	1
Protein production-related function	**Protein production pathway**	**2**	**-**
	to code for functional unit (mostly protein)	1	-
	to code for protein/RNA and regulator protein	1	-
Genomic perspective function	**Genomic function**	**-**	**2**
	to determine phenotype (direct/indirectly)	-	1
	To code for functional unit (RNA)	-	1
Total ideas		**11**	**12**

Table 6.14 showed that students who initially thought the gene was involved mainly in the production of polypeptides/protein modified its function into specifying the phenotype or the RNA as a functional unit. The selection of the terms phenotype (Charles) and functional unit of RNA (Noah) showed that students tried to highlight their effort to escape from central dogma 'DNA specifies RNA specifies protein' (Finkel, 2012). The term phenotype refers to "the observable characteristic of a cell or an organism, such as its size and shape, its metabolic functions and its behaviour" (King, Mulligan and Stansfield, 2013), and Charles clearly adopted this term to point out the various products of a gene, while Noah used the term phenotype to show the role of gene in the transmission of phenotype. In the general discussion after reading booklet Noah proposed idea of the importance of including the original idea of gene as a transmitting factor of inheritance. In the discussion (as part of learning session with educational booklet), he explained that his idea came from reading the booklet from the earliest model of gene. After reading the post-ENCODE model of gene he realised the molecular products specified by the gene became more general which was eventually related to the individual phenotype. In this case, he thought that it might be important to see the role of the gene from its proposed original role, involving in the inheritance.

Table 6. 15 UK students' idea of the gene based on pictorial definition (UK case, n=2).

The number of students who shared their respective ideas concerning the gene before and after reading the educational booklet is shown in the pre-test and post-test columns, respectively. The responses are not mutually exclusive, one individual may hold more than one idea concerning the gene. The numbers in bold (grey shading) shows the total number for each thematic idea (coding) under the same category.

Categories of gene	Coding	Number of students	
		Pre-Test	Post Test
As a part of chromosome	**a segment of chromosome**	**1**	**-**
	a segment of chromosome/a point on a chromosome	1	-
As a part of DNA on chromosome	**a segment of DNA on chromosome**	**1**	**-**
	a sequence of DNA on a DNA-constructed chromosome	1	-
As a sequence of DNA	**a sequence (segment) of DNA**	**1**	**-**
	a sequence (segment) of DNA	1	-
	a specific segment of DNA on overlapping genes	**-**	**3**
	a segment of DNA on overlapping genes	-	2
	a candidate protein coding gene (putative gene)	-	1
Total ideas		**3**	**3**

The students' revision of the concept of a gene was clearly shown in their pictorial representations (Table 6.15). They revise their image of gene by including the overlapping segments of gene on their illustration. In Charles' case, his representation of the gene shifted from a classical view to a molecular one, which matched his verbal representation (see Table 6.16 for further detail). Noah also included his idea of a putative gene, "*a segment of DNA whose protein, and its function, is not known, but based on its open reading frame, it is believed to be a gene*" (Wikipedia, 2018), into his pictorial representation which showed that a gene is a sequence of nucleotide which is identified by computer software based on the open reading frame. This matched the definition of a putative gene, "*a sequence that contains a start codon and amino acid-encoding triplets that can specify a complete polypeptide chain*" (King, Mulligan and Stansfield, 2013, p.396). The two students showed the progressive representation of a gene incorporating the HGP/ENCODE model of gene.

Table 6. 16 The changes to UK students (UK -case) concept of the gene after learning episode with the gene concept booklet

The changes on the verbal /pictorial concept of gene were used to determine the change on students' historical model of the gene. The symbol of → indicated a change. The models of the gene are (in alphabetical order) B= Biochemical-classical, C= Classical, M = Mendelian, Mo = Modern, N = neoclassical, HGP=Human genome project; EN=post Encode project. The symbol "/" shows the coexistence of two models or more)

Pseudonym	Revision to model of gene	CHANGES on		Not changed
		VERBAL concept	PICTORIAL concept	
Noah	N → HGP	to code for functional unit (mostly protein) → to code for functional unit (RNA) and involved in phenotype transmission	a sequence of DNA on a DNA-constructed chromosome → an open reading frame that overlap with other genes on a segment of DNA (candidate gene)	gene is a segment of DNA (verbal)
Charles	N/C → HGP	a segment of DNA codes for protein/RNA/regulator → a reading frame that overlap with other genes which involved directly/indirectly in specifying a phenotype	gene is a segment on a chromosome (locus) → an open reading frame that overlap with other genes on a segment of DNA which to produce RNA/polypeptides	

6.6.3. UK students' perception of the gene concept booklet

Compared to their Indonesian counterparts, the two students in the UK case preferred to the read the booklet individually. Although they were given the same instructions as the IND-2 case, they chose to start the discussion after reading the whole booklet. They did not take notes during the learning session, but did highlight or mark the important sentences, particularly on the HGP and post ENCODE eras. In the discussion, they incorporated ideas from the lectures and other reading materials they had covered into the information they read in the booklet. The main topic of discussion was overlapping genes and ORFs. These students did not have any questions regarding what they read in the booklet instead they changed and shared the information on the latest research in genetics involving the search for candidate genes which they had covered in the lectures. This part also prompted Charles to reflect on his image representation of a gene which did not match with his verbal representation. He explained that the classical representation of a gene as a segment on the chromosome was the immediate illustration that came to his mind when he asked about the gene. This suggested that for this cohort, the booklet of the gene served as a learning medium focusing students on this specific topic. By so doing, they were given a chance to incorporate their new understanding relating to the gene into their own model.

The students in this group appreciated the learning session with the educational booklet. Although they had already covered all the concepts presented in the booklet, reading booklet and being given a question relating to their own model of the gene gave them the opportunity to evaluate and develop their model to include the latest knowledge. The interview excerpt with Noah illustrated this finding.

> "*It was very interesting to read through the history of a uhm, learned about the different, uhm, how the concept of, what's the gene, what's genetics,… , so obviously from the start you got very much, uhm, namely Mendelian genetics, so you're looking at specific phenotype, and then later on you're looking at sequencing, you got more biochemical view of uhm, genetics. So, it was interesting to uhm, see not just the definition of genetics* [in the] *text book, why that current definition and how previous definition of gene… so it gave you a background of view, you can see that's change of my definition of gene. Because, although we have the concept from lectures, it produces this functional unit, we lost side of the origin of* [a gene] *being a hereditary unit… it was nice to stop and think, wait, it's a lot more to it, and it was pleasantly surprising when I was wrong* [to underestimate the original view]*, that was a nice refreshing…I quite like how each [section] explains, uhm, so this was the definition, and this influence why the definition need to change…*" (Noah/interview2/16 June 2017).

Based on the interview and observation, both students appreciated the activity focusing their attention on evaluating the concept of a gene. Regarding the booklet, students suggested a change in the booklet presentation to make it more attractive. The idea was to include a pictorial representation of the HGP model and to change the size of booklet into double-sided A5, in which they thought would be more attractive.

To conclude, for this cohort, the educational booklet of the gene concept served primarily as a conceptual resume focusing students' attention on a specific concept, the gene model. The booklet (and the learning instruction) helped students to incorporate their information on the gene from other learning sources, (the module lectures and tutorials and other reading materials) into their own solid concept of the gene. Students valued the idea of evaluating their concept of the gene using the booklet. However, they thought that the booklet would gain from the addition of illustrative images of the model representations of genes.

6.7. Reflection from the first cycle

The participating students in the UK and Indonesia (IND-2) appreciated the idea of presenting historical models of the gene in the booklet. The gene concept booklet, which was given with the specific instruction of comparing students' self-definition of the gene with the concept depicted in historical manner, activates students to evaluate, to reflect, and later to improve their own models of the gene. Although not all students had a radical change in their perspective of the gene (as shown in the case of IND-2 case), all students showed progression in their models of the gene. The presentation of the booklet included the range of years when each model was current, and this prompted students to reflect on their idea of the gene. Experiencing the learning episode with the booklet made students of IND-2 case think since they hold old conceptualisations of the gene, as they often used the Mendelian model from the 1890s, whilst students in UK case were reminded of the initial "transmitting" idea of the gene. In both cases, the gene concept booklet led the students to the idea that they needed to re-define the gene using the current definition. In terms of promoting conceptual changes to the idea of the gene, as shown in the discussion, this gene concept booklet challenged students' conceptualisation of a gene, made them dissatisfied with their current self-concept, hence made them feel the urgency to change their concept. Thus, the booklet effectively introduced students to the conditions for Posner's CCM concept changes (Posner et al. (1982); Thorley and Stofflet (1996)) and eventually experience the conceptual change.

These two cases of evaluation described above illustrate the potency of using the booklet of the gene concept in the instruction.

The concept changes shown in the two cases were slightly different, which was thought to be linked to the way they use the booklet. For the Indonesian students (IND2), the change of their concept involved changes in the perspective of a gene and the revision of supporting concepts in defining a gene. Students in this cohort used the booklet as the main source of their information regarding the model of a gene. A class discussion following reading the booklet were required and were important in terms of the learning session as they served to consolidate what students understand from the content of the booklet as well as to expand and revise information on supporting concepts used in defining a gene. While for UK students, the change involved revision of their models of the gene by linking to their factual knowledge covered during their formal lectures or other reading materials. Students regarded the booklet of the gene concept more as a medium focusing their reflection on their model of a gene. A class discussion following reading the booklet was needed but not critical in leading the changes. Students also often realised their lack of understanding as a consequence of taking the pre-test.

Because of its nature, the booklet only provided a brief coverage of historical models of the gene, therefore it has a limitation which was more suitable for use as a resumé. The UK case clearly illustrated this function of the booklet. A problem arose for students who were not yet familiar with the terms used in describing particular models of gene (most obviously, in the Modern/HGP/ENCODE model), illustrated in the Indonesian (IND-2) case. The lack of understanding of terms obstructed students in having conceptual changes, though they were dissatisfied with their existing concept of gene. Most of the terms were needed to explain during the class discussion made the booklet served more as a frame of reference to explain the genetic concepts regarding each historical model of a gene.

Students in both cases valued the idea of learning about the concept of the gene with the booklet, therefore, no further revision to the content is necessary. However, they suggested to improve booklet presentation which encourage their initial motivation to read the booklet and will engage them more in learning the concept. Many recommendations were on the incorporating more pictorial representations of the models of the gene. A change in the size of the booklet (into A-5) was also suggested to

give the students a sense of a simple book. The two ideas were implemented in the revision of the booklet.

6.8. Revision of the booklet of the gene concept

Reflection on the first cycle led to a plan for revising the booklet. Based on recommendations, no change in the textual content of the booklet was made, but some wording and pictorial representation was added, and the physical appearance of the booklet modified (Appendix D-3).

1. Redesigning the concept and content presentation of the booklet of the gene concept

The revised content of the booklet still maintains the presentation of historical models of the gene (Gericke and Hargberg, 2007). As on the first version, this is followed by sections on Human Genome Project and post ENCODE models of the gene which were developed from the updated model of the gene (as proposed by (Smith and Adkison, 2010) and post-ENCODE definition of gene (Gerstein *et al*, 2007).

No fundamental changes were made to the content of each section, but there were some revisions in how the content was written. Many of the IND-2 students required an extended explanation of the Hershey and Chase experiment in the Biochemical era, and additional information on the principles of their work was added to the second version. Textual explanation on HGP and ENCODE was rewritten (although there were no additional concepts). In the section on the modern era, an additional diagram showing that computer software is used to determine the nominal/putative gene by identifying open reading frames (ORFs). During cycle 1, IND-2 students still retained some misunderstandings of which were thought be connected to how the booklet presents information. These issues were used to revise the wording and or add additional information. Students misunderstanding was related to thinking genes as not located on a fixed locus of chromosome, and that DNA occupies a certain locus of a chromosome. The revision that has been made was based on addressing those misconceptions by presenting information on the structure of transposons (from the HGP era) and adding pictorial representations to show a chromosome is a condensed form of DNA (from the neoclassical model), respectively. Further additional information was included on the explanation of transplicing mechanisms (from the HGP model). Other misconceptions found on IND-2, such as misconceptions on the structure of DNA, and sister chromatids

(alleles) did not counter on this booklet of the gene due to the space limitation and the purpose of booklet of gene to revise students' perception to the gene. Table 6.17 presents a summary of the revisions of the booklet.

Table 6. 17 A summary of content revisions to the booklet of the gene concept

Historical model	Verbal/pictorial content on previous version (Ver.1)	Verbal/pictorial content on the latter version (Ver.2)
Mendelian (early 1900s)	**Textual:** An emphasis on the abstract concept of Mendelian factor of heredity **Pictorial:** A picture of individual CROSSING involving MENDELIAN FACTOR of heredity	**Textual:** The same concept with the first version **Pictorial:** Additional picture showing the representation of abstract Mendelian factor of heredity
Classical (1911-1941)	**Textual:** An emphasis on the physical concept of the gene as a dimensionless point/a segment/a locus on a chromosome. **Pictorial:** A "BEADS ON A STRING" act as/specifies ENZYME which determine PHENOTYPE	**Textual:** The same concept with the first version **Pictorial:** Additional picture showing the equivalent of representation of "beads on a string" with a series of segments of gene on a chromosome
Biochemical (prior to 1953)	**Textual:** Chromosome (genetic material) was made of DNA (*it does not link to DNA double helix structure).* **Pictorial:** GENE (represented as four bases of DNA) specifies ENZYME specifies PHENOTYPE	**Textual:** Adding explanation on the work of Hershey and Chase in determining DNA as genetic material **Pictorial:** Same with the first version
Neo-classical (prior to 1970)	**Textual:** The discovery of double helix DNA Gene (segment of DNA) specifies RNA specifies PROTEIN **Pictorial:** DNA specifies RNA specifies PROTEIN	**Textual:** The same concept with previous version **Pictorial:** Additional picture showing the four bases constitutes a double helix DNA
Modern (1970-2000)	**Textual:** Gene as a segment of open reading frame of DNA **Pictorial:** A structure of open reading frame	**Textual:** The same concept with the first version **Pictorial:** Additional picture showing DNA (ORF) specifies RNA specifies polypeptide, the use of software program in finding the candidate gene
HGP (around 2000)	**Textual:** Overlapping genes, transcription of junk DNA, combination of mRNA transcript of two or more genes (transplicing) **Pictorial:** -	**Textual:** The same concept with the first version **Pictorial:** ORF inside double helix DNA (genomic); RNA transplicing
The Post ENCODE project* (2007-present)	**Textual:** Active transcription sites making non-protein coding RNA, overlapping genes to produce a specific phenotype/function **Pictorial:** DNA makes RNA makes protein; RNA makes protein; DNA makes RNA (various products of genes)	**Textual:** the same concept with the first version **Pictorial:** the same picture with the first version

*THE POST ENCODE (Encyclopaedia of DNA elements) definition of gene has just been proposed and has not been accepted as the consensus paradigm definition

2. Determining a title for the booklet

The revised version of booklet of gene concept preserved the title of "A brief definition of the gene".

3. Finishing technical presentation

The revisions to the booklet of the gene concept were concluded by changing the A-4 size into A-5 size. Each section was presented on two pages, side by side (see Figure 6.12) to make information on the same section easier to read. The same weight of paper was used as the first version of the booklet.

4. Reconstruction of booklet of the gene concept

The second version of booklet was created following its re-design blue print (see Figure 6.12). All other materials related to the booklet were unchanged, including the purpose of and accompanying activities to the booklet.

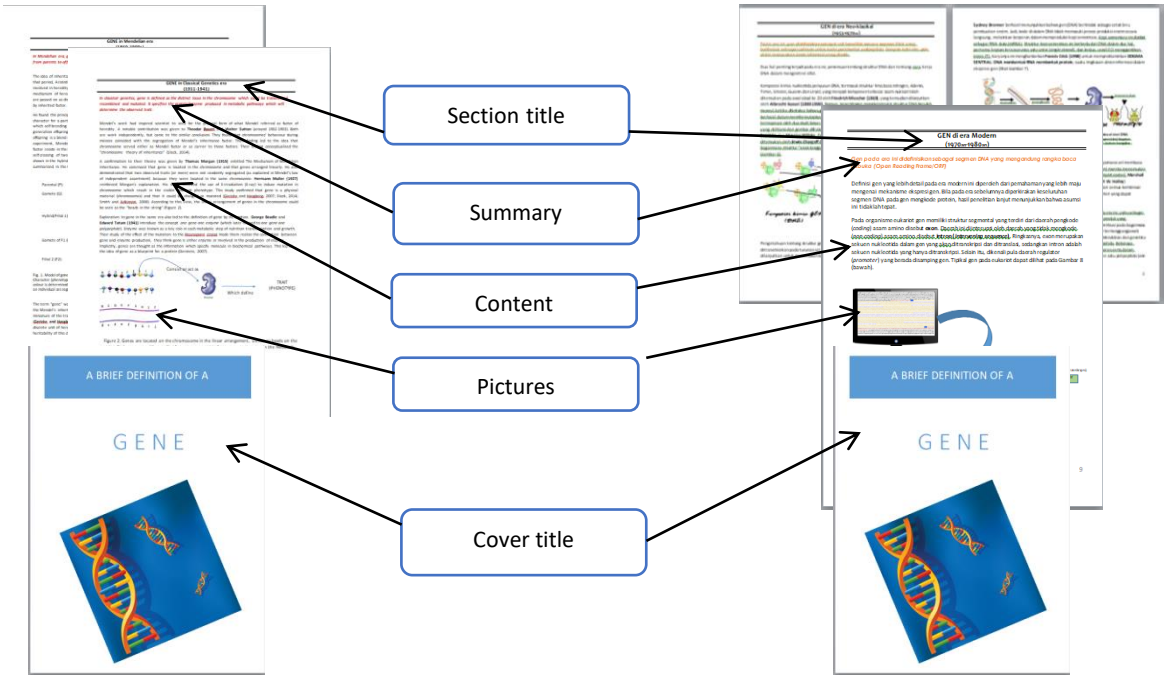


Figure 6. 12 The presentation of the revised version (right) in comparison to the previous version (left). *Improvement were made on reducing the size of the booklet paper (A5), presenting each era on two pages, and giving bigger proportion to the images.*

6.9. The impact of the revised version on reducing students' misconceptions of the gene concept

The revised version of the booklet of gene concept was trialled on a group of Indonesian students (IND-3, n=9). Students participating were enrolled on the same degree programme as the IND-2 cohort of students (first cycle). They were taking a genetics module in the following academic year to the first cohort. The discussion will first focus

on identifying students' existing conceptions of gene and continues with the description of how the booklet helped them to develop their models of the gene.

6.9.1. Indonesian Students' (IND3-case) existing conception of gene

Students' existing conceptualisation of the gene served as the basis for evaluating to what extent a learning session using the booklet helped them to improve their understanding. Students' conceptualisation of the gene was assessed from their verbal and diagrammatic representations of a gene. Any misconceptions in supporting concepts are considered later in this section.

Students in this group (IND-3) had a slightly different pattern for modelling the gene through their verbal description compared to their predecessor (IND-2) cohort. This was first identified by comparing the most common words associated with the gene. Figure 6.13 shows the three common words used to define the gene, were "located", "genetic", and "DNA". This showed that the majority of students in this group had acknowledged a relation between gene and DNA. However, they commonly cited DNA as the location of the gene, instead of recognising the gene as a segment of DNA. This led to the viewing of the gene as genetic material and genetic substance (which was the reason for the high prevalence of the word "genetic") located in the DNA.

Figure 6. 13 Common words used by Indonesian students (IND-3; n=9) to verbally define a gene prior to learning with the Booklet of the Gene concept. *The greater frequency is shown by the bigger size of words. Students' original responses were translated into English prior to analysis. The word "gene" was removed since it was the word in question. Also, conjunctions and other determiners were removed*

Although the majority of students had mentioned DNA in their description of the gene, terms relating to the classical model of the gene, such as “chromosome”, “trait”, “parents”, “transmit” and “descendants” were also prevalent (see Figure 6.13). This suggested that students held a hybrid classical-molecular model of the gene. This was confirmed through categorisation of their conceptualisations based on historical models of the gene (Table 6.18). Two thirds (6 out of 9 students) of participants had a hybrid model, either reflecting the Neoclassical and Mendelian or the Neoclassical and Classical models. Another student held a biochemical model of the gene where she thought of the gene as a trait carrier (classical) located in the DNA without showing a representation of a DNA molecule on her pictorial representation. The remaining three students, one showed an obvious classical model of the gene and another showed the neoclassical model. Thus, in terms of the variety of conceptualisation of the gene, it could be said that this particular cohort shared a similar characteristic with the IND-2 group. The differences lay in the proportion of students using a classical model of the gene which was found to be higher in IND-2.

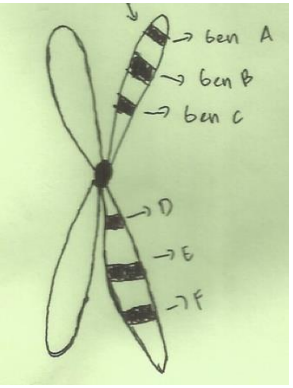
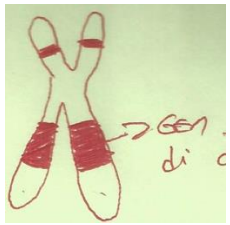
6.9.2. Impact of the gene concept booklet: IND-3

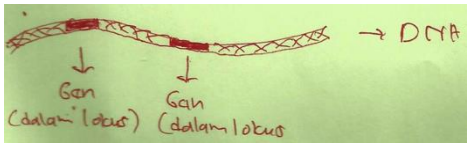
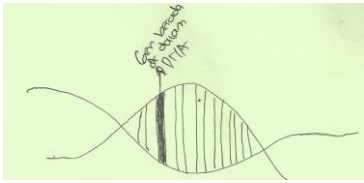
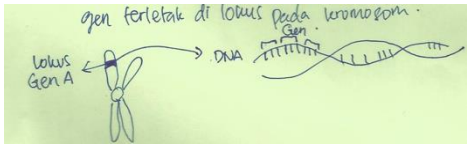
The way booklet changed students’ concept of the gene in each particular cohort was first identified by looking for any changes to their model of gene following their learning session using the booklet. This was followed with an investigation into the particular presentation and/or content of the booklet which led students to undergo that change.

The analysis used three approaches, verbal descriptions of structure, and function and a pictorial representation of the gene, to show students’ progression in their understanding of the concept of the gene from classical to molecular. This was particularly observed when conceptualising ideas of gene structure (Table 6.18).

Table 6. 18 Various historical models and conceptualisations of the gene from students in the Indonesian case (IND-3) based on their individual verbal and pictorial definitions of the gene (n=9)

The table shows the historical model of the gene constructed from students' verbal and pictorial conceptualisations of a gene. The questions were given just before students used the booklet (pre-test). A hybrid view model is shown by the two models combined by (&); in this case the Neoclassical & Classical model of the gene. The number in brackets [ ] following each model refers to the number of students for that particular model. Words highlighted in blue show the associated description of the students' verbal definition with its description (second column). The interpretation of the students' pictorial definition of a gene is given in the pictorial description (third column).

Historical model of the gene	***Description of concept of gene (Verbal)***	***Description of concept of gene (pictorial)***	***Sample***	
			Verbal definition*	***Pictures***
Classical [1]	**Structure of genes:** - A genetic code on the chromosome **Function of gene:** - trait determination - transmission	**Gene is drawn as:** - a specific segment on a chromosome	*Gene is **a genetic code** which **carries genetic information concerning trait** from parents to the descendants within generation. **Gene codes for certain trait of parents**, it will pass to the descendants, which makes them similar to their parents. Gene is **located on certain loci on the chromosome**, which made not all sections of chromosomes are genes. **Each gene codes for one specific trait**. Thus, all genes code for all traits which is possessed by an individual **(Wawan/Pre-test).***	 **(Wawan/Pre-test)**
Biochemical-classical [1]	**Structure of genes:** - a trait carrier - located in DNA **Function of gene:** - transmission	**Gene is drawn as:** - a segment on chromosome	*Gene is **a trait carrier** which is **transmitted** from parents to their offspring. The gene can either be dominant or recessive. **It is located in the DNA.** **(Andar/Pre-test)***	 **(Andar/Pre-test)**

Neoclassical [1]	**Structure of genes:** - a material in DNA **Function of gene:** - as metabolic precursor of enzyme/hormone - transmission	**Gene is drawn as:** - as a segment on DNA (inside a locus on the DNA)	*Some **specific material** which is stored and used as **precursor of metabolism**, particularly enzyme and hormone. Also, **it can be transmitted** to the descendants. Gene resides on the locus (specific location) in the DNA* (**Intan/Pre-test**)	 **(Intan/Pre-test)**
Neoclassical & Mendelian [2]	**Structure of genes:** - a unit of inheritance in DNA - a cluster of DNA **Function of gene:** - transmission	**Gene is drawn as:** - a base pair on a segment of DNA	*Gene is **a genetic material** which **can be transmitted** from parental to offspring. Gene also **a unit of inheritance** for organism, gene is **located in the DNA**. (**Humaira/Pre-test**)*	 **(Humaira/Pre-test)**
Neoclassical & Classical [4]	**Structure of genes:** - a genetic material (DNA) - a sequence of DNA [e.g. Dorothy] - a heredity information on DNA/chromosome - a heredity substance - pairs of nitrogen bases [e.g. Cantika] **Function of gene:** - transmission [e.g. Cantika] - trait determination [e.g. Dorothy] - genetic variation inducer	**Gene is drawn as:** - a segment on chromosome - Each triplet nucleotides of a DNA segment on a locus of chromosome [e.g. Dorothy] - segment on chromosome contains ATGC (nitrogen base) [e.g. Cantika] - a (series of)ATGC on a segment of a chromosome	*Gene is **a substance of heredity** which **carries traits** of living things. Genes composes human body and located in the nucleus. Gene is comprised of nitrogen base pairs. (**Cantika/Pre-test**)* *Gene is **a DNA sequence** which contains genetic information. It **codes for a certain trait,** and can be inherited to its descendant.(**Dorothy/Pre-test**)*	 **(Cantika/Pre-test)**  **(Dorothy/Pre-test)**

**Verbal definitions depicted were the English translation of the original verbal definition pre-test*

After reading the booklet none of the students defined the structure of the gene at the symbolic or cellular level. The structure of a gene was related to DNA, either as a molecule or a segment or part of DNA (including the transcriptional unit). There were students, who related the structure of genes using a genomic perspective (e.g. by mentioning the projection of gene as a molecule of DNA and/or RNA or including the functional intron). The inclusion of RNA (as the genetic material for viruses) in the definition of gene showed that students tried to incorporate the post-ENCODE model of the gene into their model (Gerstein *et al*, 2007).This also included acknowledging the role of the intron. Both of these concepts were discussed in the last section of the model of gene in the booklet.

One particular student, Yono, gave a general idea of the structure of the gene as the identity of living things (see Table 6.19). However, it was confirmed through the interview that his definition of a gene was carefully chosen to reflect an acknowledgement of the genomic structure (discussed later in this section), so it was categorised as having a genomic perspective.

After the learning session with the educational booklet, some students incorporated the molecular function of the gene (relating to the production of protein and other molecular products) into their conceptual understanding. The number of ideas relating the function of a gene as a trait carrier or trait determiner in the post test were reduced (Table 6.20). Two abstract ideas related to the function of the gene were found on the post test. One of them stated that a gene has a function in programming life of an individual, while the other stated that a gene has a function as an individual information carrier. Since the first idea was put forward as part of Yono's understanding of a gene as one contributing factor that works simultaneously with other genes in controlling the life of an organism (Observation notes/R4/24 January 2018), his idea was categorised as being a genomic perspective. Meanwhile the second idea was part of Emma's statement on a definition of a gene "…*The bases* [of DNA/RNA] *is the information carrier of a living thing*" (Emma/Post-test/27 January 2018), which show her hybrid understanding of molecular-classical gene, thus it was categorised under the "transmission of trait".

Table 6. 19 Indonesian students' ideas of the structure of the gene based on verbal definitions (IND-3 case, n=9).

The number of students who shared their respective ideas concerning the gene before and after reading the educational booklet is shown in the pre-test and post-test columns, respectively. The responses are not mutually exclusive, one individual may hold more than one idea concerning the gene. The numbers in bold (grey shading) shows the total number for each thematic idea (coding) under the same category.

Categories of gene structure	Coding	Number of students	
		Pre-Test	Post-Test
Symbolic (abstract)	**a unit of inheritance**	**1**	**-**
	a substance of inheritance	1	-
Cellular	**a part of chromosome**	**2**	**-**
	a genetic code on a locus of chromosome	1	-
	a mutable/recombine-able substance	1	-
Cellular/ Molecular	**a genetic material**	**3**	**-**
	a genetic material (DNA/chromosome)	1	-
	a genetic material (DNA)	2	-
Molecular	**a molecular substance**	**1**	**1**
	protein determining substance	-	1
	a long sequence of nitrogen bases	1	-
	a DNA unit of inheritance	**2**	**-**
	a unit of inheritance on the DNA	2	-
	a sequence of DNA	**2**	**1**
	a sequence of DNA	1	1
	a cluster of DNA	1	-
	a transcriptional unit	**-**	**4**
	a transcriptional unit	-	4
	a genomic perspective	**-**	**4**
	a molecule of DNA or RNA	-	1
	an identity information of living things	-	1
	a transcription unit of DNA & RNA	-	1
	a functional intron	-	1
Total ideas		**11**	**10**

Table 6. 20 Indonesian students' ideas of the function of the gene based on verbal definitions (IND-3 case, n=9).

The number of students who shared their respective ideas concerning the gene before and after reading the educational booklet is shown in the pre-test and post-test columns, respectively. The responses are not mutually exclusive, one individual may hold more than one idea concerning the gene. The numbers in bold (grey shading) shows the total number for each thematic idea (coding) under the same category.

Categories of gene function	Coding	Number of students	
		Pre-Test	Post Test
Trait-related function	**Transmission of trait**	**7**	**3**
	active transmission of trait/genetic information	2	2
	passive transmission of trait/genetic information	5	-
	an individual information carrier	-	1
	Trait determination	**4**	**2**
	to specify a trait	4	2
Protein production-related function	**Protein production pathway**	**-**	**4**
	to code for protein/polypeptides	-	2
	to specify amino acids	-	1
	to produce RNA-protein	-	1
Genomic perspective function	**Genomic function**	**-**	**3**
	as a life programmer	-	1
	to produce a conformation with non-genic	-	1
	To code for functional phenotype	-	1
Other function	**Genetic variation inducer**	**-**	**1**
	Genetic variation inducer	-	1
Total ideas		**11**	**13**

Students' progress on formulating a model of the gene was also shown by their diagrammatic representations (Table 6.21). None of the students incorporated the idea of showing the gene as a segment of a chromosome. Following the learning session, there were some students identified a gene as a transcriptional unit of DNA; this was not found in the pre-test. In this case, it could be said that students improved their model of a gene by changing from a molecular-classical view into a complete molecular model.

A summary of the individual changes to the students' models of the gene is presented in Table 6.22. The table shows the classification of models of the gene based on their historical context. From solely analysing their verbal and pictorial representations of the gene, four students could be categorised as integrating the HGP model (including in combination with the classical model). To investigate whether this change in the concept of gene was "fruitful" according to the conceptual change framework (Posner *et al*, 1982), students were interviewed about their actual concept of the gene within 1-3 days after they had done the post-test.

Table 6.21 Indonesian students' ideas of the gene based on pictorial definitions (IND-3 case, n=9).

The number of students who shared their respective ideas concerning the gene before and after reading the educational booklet is shown in the pre-test and post-test columns, respectively. The responses are not mutually exclusive, one individual may hold more than one idea concerning the gene. The numbers in bold (grey shading) shows the total number for each thematic idea (coding) under the same category.

Categories of gene	Coding	Number of students	
		Pre-Test	Post Test
As a part of chromosome	**a segment of chromosome**	**5**	**-**
	a segment of chromosome/a point on a chromosome	5	-
As a symbol of reservoir of gene	**A substance**	**-**	**2**
	A series of unit	-	1
	A series of unit on DNA/RNA	-	1
As a part of DNA on chromosome	**a segment of DNA on chromosome**	**-**	**1**
	a sequence of DNA on a particular segment of chromosome	-	1
As a sequence of DNA	**a sequence (segment) of DNA**	**4**	**3**
	a sequence (segment) of double helix DNA	-	1
	A triplet nucleotide on a segment of DNA	1	-
	A base pair on a segment of DNA	1	1
	An ATGC bases	2	-
	An ATGC bases that bound to sugar-phosphate	-	1
	a transcriptional unit	**-**	**4**
	a transcriptional unit (promoter-exon-intron-exon-terminator)	-	4
Total ideas		**11**	**9**

Table 6.22 The changes to Indonesian Students (IND-3) concept of the gene after learning episode with booklet of the gene concept

The changes to the verbal /pictorial concept of gene were used to determine changes to students' historical model of the gene. The symbol of → indicates a change. The historical model of the gene was stated in abbreviation, with symbol "/" showing the coexistence of two models or more. The models of the gene are (in alphabetical order) B= Biochemical-classical, C= Classical, M = Mendelian, Mo = Modern, N = neoclassical, HGP=Human genome project; EN=post Encode project)

Pseudonym	Revision to model of gene	CHANGES on		Not changes
		VERBAL concept	PICTORIAL concept	
Maria	N/C → HGP	genetic material (DNA) on a locus of chromosome to transmit/determine a trait → a transcription unit of a genomic structure (DNA/RNA) & an intron to induce variation	A (series of) ATGC on a segment of a chromosome → a series of exon which is alternate by intron in a transcription unit	
Cantika	B → N/C	a nitrogen bases pairs as heredity substance to carry a trait → a polypeptide/protein-determining-substance to determine a trait	A (series of) ATGC on a segment of a chromosome → gene is a (sequence of) ATGC on a phosphate-sugar (backbone)	
Andar	B → Mo/C	a trait-carrying-DNA involved in transmission → a transcription unit involved in transmission	a segment on a chromosome → all exons of a transcription unit located on a locus of a chromosome	
Humaira	N/M → Mo	a unit of inheritance on genetic material (DNA) involved in transmission → DNA contains exon and intron to specify amino acids	-	a base pair on a DNA double helix
Yono	N/M → HGP	a cluster of DNAs on a chromosome that involved in transmission → an identity information of living things as a life instruction programme	a segment of DNA → a series of unit	
Intan	N → Mo	specific material in DNA that acts as precursor of enzyme/hormone → a transcription unit (ORF) to code for RNA/protein	a segment on the DNA → a transcription unit	
Dorothy	N/C → N/C	a sequence of DNA to transmit and determine a trait → a sequence of DNA involved in transmission	Each triplet nucleotides of a DNA segment on a locus of chromosome → a DNA segment of a locus on a chromosome	

Wawan	C → HGP/C	genetic codes in a locus on the chromosome to determine a trait → DNA/RNA to code for a phenotype	as one of segments (loci) on a chromosome → a series of unit on the DNA, and the RNA	
Emma	N/C → HGP/C	a heredity information-bearing- DNA/ chromosome involved in transmission and genetic variation → a transcription unit on DNA/RNA (putative gene); a non-putative gene to carry information/to code for protein/to determine a trait	a segment on a chromosome → a transcription unit on the locus of chromosome	

Four students had deliberately changed their conceptualisation to integrate the more modern concept of gene, the HGP model (Tabel 6.22). One student, Yono, totally changed his idea of the gene with the adoption of the HGP model. He changed his idea of a gene from "a segment of DNA involved in the transmission" into "the identity information of the living programme". Although his definition seemed to be a more general concept of a gene, from the interview, he showed that this new understanding of a gene was conceptualised through understanding the models of a gene up to the HGP era.

In: What did you get from reading the booklet?

Yo: "When I first read it, I got confused. I was shocked. I just found out that my thought [of gene] was that shallow. There is a "deeper ocean" to go. I am still on the surface. When I think of gene, gene is a transmittable genetic material. That's what in my head. But, it is not that simple. And I said… Well, it appears that gene contains information to specify protein, to produce polypeptide, and eventually to differentiate me with other individual. So, it shocked me".

…

Yo: When I read in modern era, I just knew that [a gene] it's not only genetic material, there is also an open … what is it …oh, open reading frame (laugh). There is promoter, exon, oh well I am not sure whether exon is part of that too? Well, there were many things I read and absorb.

…

Yo: And yeah, from Human genome project. Well, oh, we just the same, I presumed. What make us [human] a living thing, maybe just the same with the factor that makes an earthworm a living thing. Thus, what make us different? That question just popped up in my mind. And I just realised that it could be… from 2007 till now…well, we are… junk DNA is useful (laugh) so… I just knew.

In: So, you think that is what you got from the booklet?

Yo: Yes, the three last chapters, uhm… sections, really hit me. If it is for the first section, like… uhm..discovering DNA, and there was an idea of inheritance before Mendel, Aristoteles had that idea. Well, it just an idea, but he started everything. But I guess, [I like] the complexity that comes at the end.

(Yono/Interview3/29 January 2018)

The interview excerpt of Yono shows that he had taken into account what he read from the booklet, and later incorporated it into his understanding of the gene to produce the new definition. Although his definition still shows some incorrect understanding of supporting concepts (e.g. he was not sure whether an exon is part of a gene in the HGP model) and he did not clearly describe the mechanism which led to the production of an individual's genomic identity, but the sequence of his thoughts showed the four

conditions of conceptual change (Posner *et al* (1982); Thorley & Stofflet (1996)). First, he experienced the dissatisfaction of old concept which was reflected on his statement: "*I was shocked… there is a "deeper ocean" to go, I am still on the surface*". Second, he found the intelligibility of the new idea, as he said:" *I just knew that* [a gene] *it's not only* [transmittable] *genetic material, …* ". Third, he showed the plausibility of the concept, "*What make us [human] a living thing, maybe just the same with the factor that makes an earthworm a living thing. Thus, what make us different? That question just popped up in my mind. And I just realised that it could be… from 2007 till now…well, we are… junk DNA is useful (laugh) so… I just knew*". And, finally he saw the effectiveness "fruitful" of the new idea when he integrated that into his model of gene: "*gene contains information to specify protein, to produce polypeptide, and eventually to differentiate me with other individual*".

Two of three other students who changed their idea of the gene by incorporating the genomic perspective showed changes of concept, however it is different from the first case. Emma and Wawan believed that there was a new way to understand the gene in a genomic view, but they tended to make a hybrid view with their existing concept of a gene. Wawan, preferred the concept of a gene as:

> *"a locus on the chromosome…which specified a protein in a metabolism pathway. This kind of metabolism works so that we are what we are now. That's a more preferable concept of gene for me*" (Wawan/interview2/28 January 2018).

Similarly, Emma, preferred to include her existing concept of gene.

> *"a discreet…heredity factor…because it is transmitting something, so my* [future] *students or others would now what is gene. It is inheritance…And then, I will go with neoclassical and modern,* [DNA with] *the ladder, and. what it is called… em, ORF…I will relate its definition with Mendelian gene, then DNA, yah well its structure…in short, what is gene in simple definition, and then its structure, like zoom out the double helix DNA, and a bit deeper, the nucleotides, and then the bases."* (Emma/interview2/28 January 2018).

In this case, the three students compromised their new ideas of the gene with their existing conceptualisations. In so doing, they showed the three conditions of concept change according to Posner's CCM model (Posner et al., 1982; Thorley & Stofflet, 1996), the dissatisfaction of their existing concept and the realisation of the intelligibility and plausibility of the newly introduced idea. However, the radical changes to their concept were not take place since they thought they lacked understanding to the new terms (as showed by their interview). Thus, it could be said

that they still experienced a change of understanding (see Table 6.22), but in a different way compared to Yono.

Although the degree of changes in the case of Yono and the other three students are different, they all show awareness to the lack of their idea of gene. The self-awareness arises from comparing and reflecting their current understanding of the gene with various concepts of gene provided on the booklet. The awareness to their self-concept is the critical point to experience concept change. Students who have misconceptions did not aware that their concept were incorrect, such as revealed in research conducted by Hoban and Nielsen (2013).

Interestingly, the self-awareness to the lacking current conceptions of the gene did not only showed by this group (IND-3), but consistently showed by the IND-2 cohort, for example in the interview excerpt of Bona (p.216), Karin (p.217), and Vira (p.219), as well as by the UK participant, Noah (p.228). Thus, the learning process with the gene concept booklet, which promoted students' self-awareness to change their conceptions, are valuable for instigating students' conceptual change.

As revealed in the previous cycle, the historical concept of the gene presentation on the booklet were not the only reason for the concept changes. There were students who initially did not engage with the content on the booklet, for example Intan and Cantika. They did not read the full text of information, instead they use a resumé at the beginning of page and the available pictures to understand each model of the gene. In the interview, both students claimed that they began to pay more attention to the information on the booklet during class discussion when their friends asked questions that attracted their curiosity (Observation notes/26 January 2018). Thus, the self-awareness which led to the concept changes may be triggered during students read the booklet as well as during classroom discussion. Whichever event, the changes were initiated by the instruction to compare their existing concept of the gene with the various conceptualisation of the gene on the booklet.

The trigger point for the class discussion for IND-3 students was different from that in the first case (IND2). Students in the first case (IND-2) were more interested in discussing the connection between DNA and chromosomes, particularly when they discussed the biochemical-neoclassical model of the gene and discussing the detail of DNA segments as units of transcription when they covered the modern model of the gene. This was different from the trigger point of discussion for IND-3, where they were more interested when discussing the lower number of putative genes compared to

that expected in the HGP era. However, both groups benefited from the class discussions as part of generating their conceptual change. Students in both groups mentioned that the class discussion provided them with a sort of confirmation for their understanding of technical terms which they were not confident about.

6.10. Reflection and recommendation

Reflecting on the findings from students' evaluation of the gene concept booklet, this booklet has potential in initiating improvement in students' understanding of the gene. Students in all three cases (IND-2, UK, and IND-3) were assisted in making a conceptual change by promoting awareness to the lacking idea of their existing concept of the gene through comparing their idea with the historical conceptualisation of gene presented on the booklet. Students were supported in re-evaluating their ideas, and later to conceptualising their model of the gene based on the reflections of what they considered as lacking in their existing concept of gene.

Similar to students in the first group (IND-2), the concept changes experienced by IND3 involved both the changes to their model of the gene, and the revision of the supporting concepts (e.g. the structure of DNA) in defining their model of gene. Both groups of students benefitted from the content of the booklet in changing their models of a gene. The in-pair and class discussions after reading the booklet allowed students to confirm their understanding of the gene concept which they read in the booklet and to elaborate the revision of their model as well as their supporting concepts in defining a gene.

Students, in both Indonesian case (IND-2 and IND-3) mainly revised their relation of DNA, gene and chromosome from the discussion. This was reflected by many students using DNA in their model of gene. The presentation of the booklet which included the range of years for each model caused students to think that they held older, outdated models of the gene. This led the students to the idea of they need to describe the gene using a more current definition. Not all students had a radical change to their perspective of the gene, however, all students showed progression in their models of the gene. Due to the limited number of participants in UK case, it was not possible to generalise on the usefulness of the booklet for changing UK students' understanding of the gene concept. However, the UK case gave an insight to the benefit of the booklet to assist students in improving their conceptualisation of the gene, regardless the different starting-point in their understanding of the gene concept.

The two cycles of development of the booklet still left some ideas for future revisions to the booklet. The pictorial representations for modern model of gene in the booklet might lead students to misconceive the promoter segment as being included as one complete structure of the gene. This was evidenced from evaluating IND-2 and IND-3 students' models of the gene in their post-test. To prevent the same misunderstanding happening in the future, a revision to exclude the promoter from the pictorial representation in the modern model of the gene will be made.

The evaluation test, which asked students to describe their understanding of the gene by verbal and pictorial representations gives two advantages; apart from merely acting as an evaluation tool to identify which historical model of the gene students held, the test could also be used to reveal students' misconceptions regard to the supporting concept to the conception of gene (e.g. students' representation of structure of chromosome to explain their classical model of gene). The test could also be applied in the learning process without necessarily using the booklet of the gene concept.

Asking students to reflect on their concept of the gene with the various ideas of the gene in the booklet showed that it successfully promoted students' self-awareness to the inadequacies of their current concept of the gene, and later leading them to remedy their conception. Not all students showed radical changes of their concept, however, all students show an attempt to improve their concept of the gene. The successful strategies to remedy concept of the gene was gained through instigating self-awareness, which also shown by the strategies for conceptual changes mentioned by Bahar (2003).

This research also showed that teaching the concept of the gene or genetics in general using historical models of the gene concept is as valuable as teaching them using conceptual approach (Corebima 2001) or inverted curriculum (Dougherty, 2000). The booklet also showed that the importance of teaching the concept of the gene in an historical approach, as suggested by Boujeema (2000), could be presented in summary as a booklet.

Chapter 7 – Overall findings, conclusions and implications for future research

Overview

This chapter ties together previous chapters to discuss the overall findings and to draw the overall conclusions of this study. The chapter is divided into three sections. The first section presents the overall findings from the three different projects developing resources aimed at tackling misunderstanding of basic concepts of genetics. The discussion of the findings is made based on responses to each research question of this study. The first subsection shows the findings on the ways of using information from common misconceptions to develop the targeted educational resources. The second subsection includes the results of using concept inventory tests or equivalents to depict students' misconceptions. This provides a basis for evaluating the effectivity of using published common misconceptions in predicting students' misconceptions in the classroom. In the third subsection, is focused on the effectivity of developing the educational resources based on the changes in students' misconceptions and the students' responses to the resources. The last subsection within the first section concludes the advantages of incorporating comparative cases in evaluating the effectivity of the resources. The second section presents a discussion of the limitations of this study, including limited generalisability of the findings, the limitation of the methods in developing the resources and the limitation of researcher interpretation of data. The final section presents a discussion on how the findings of this study contribute to the suggested teaching methods for three selected topics of meiosis, Mendelian inheritance and concept of a gene in the genetics instruction or biology in general. In the same section, recommendation for using an applied alternative approach to action research in developing teaching resources for other subjects is discussed

7.1 Overall Findings

Having misconceptions has been shown as the main obstacle in achieving understanding in associated concepts in biology, including genetics. Conceptual understanding is achieved by helping the learner to reconstruct knowledge to gain the scientific concept. This thesis has been concentrated on developing targeted resources to address misconceptions in three selected fundamental concepts in genetics: meiosis, Mendelian inheritance and the concept of a gene and analysis of their success. The findings on the effectiveness of each targeted resource have been discussed in Chapters 4, 5 and 6, respectively. The three studies show the overall effectiveness of constructing targeted teaching resources in addressing students' misconceptions of key concepts of genetics. The overall findings for this thesis are discussed based on the responses to each research question.

7.1.1. Using common misconceptions information in developing targeted resource

This section relates to research question 1: How is information regarding common

misconceptions used to develop the targeted educational resources?

The extensive literature on misconceptions (as discussed in section 4.1, 5.1 and 6.1, respectively) served as valuable source to develop educational resources targeting to amend misconceptions. Reviewing the development processes of the three targeted educational resources in this thesis, there are two methods for incorporating information of common misconceptions in the design and creation of the targeted resources, as content building, and content scaffolding (summarised in Table 7.1). The difference in the way the information is utilised in the resource development process was due to the nature of the misconceptions and the purpose of the resource development.

For content building, the common misconceptions informed the development of each scene which then create into one integral story of meiosis as the meiosis video. Misconceptions of meiosis were revealed to be related to its subordinate concepts, i.e. the supporting concepts to understand the chromosome behaviour during meiosis (see discussion in section 4.2). Detail information from each common misconceptions of one particular subordinate concepts influence the way of presenting the content of the video to overcome it. For example, the term "haploid" which commonly misidentified as "having unduplicated structure of chromosomes" (Kalas *et al*., 2013) was tackled by showing the haploid cell which have both unduplicated and duplicated chromosomes on the meiosis video. Although several researchers have created their resources to targeting the revision of one specific concept (e.g. Luo, 2012; Rindos and Atkinson, 1990), the format of the meiosis video which illustrates the role of meiosis in creating genetic diversity allows demonstration of all related common misconceived subordinate concepts.

Another way to use information from common misconceptions is to utilising it to create a higher framework to scaffold the content. This is demonstrated in the development process of the inheritance cards activity and the gene concept booklet (see Chapter 5 and 6, respectively). The former resource is built based on the premise that the students lack an understanding in seeing the connection between meiosis and Mendelian inheritance (Allen and Moll, 1986). This lack of understanding leads students to have misconceptions in Mendelian inheritance, for example considering that the segregation process of alleles exclusively occurs in monohybrid crosses (e.g. Nusantari, 2014). Thus, this information underlies the process of creating the resource.

Table 7. 1 A summary of the development of resources showing the way information from common misconceptions is utilised.

Name of Educational resoources	Purposes of Educational resources	Example of common misconceptions	The way it is informed the development process	Strategy applied
-The meiosis video	• To show the scientific concepts of important subordinate concepts of meiosis • To show the way meiosis contribute to the genetic diversity	**Subordinate concepts:** • To determine haploid from the structure of single chromosome (Kalas *et al*., 2008) • Confusing in differentiating sister chromatids from homologous pair (Kindfield, 1994) **Mechanism of meiosis:** • Seeing stages of meiosis as independent process (Smith *et al*., 2008)	• Showing haploid both in single and duplicated structure of chromosomes • Providing representational picture of sister chromatids and homologous pairs • Creating continuously available labels for the stages of meiosis, signposting the changes of stage	I – content building
The inheritance cards activity	• To show a link between meiosis and Mendelian inheritance	• Students are good at doing mathematical calculation in a crosses, but poor in understanding the conceptual idea behind the process (Stewart, 1982)	• Creating the material (cards) which show meiosis and enable to perform crosses	II – content scaffolding
The gene concept booklet	• To promote advance model of gene	• Students have the hybrid conceptions of gene, where they combine classical function of gene with molecular structure of gene in a model of gene (Agorram, 2010)	• Creating the material (booklet) based on historical concept progression of model of gene, emphasising the gene structure and function	II – content scaffolding

The same strategy was applied to create the booklet of the gene concept. Although the information of common misconceptions in concepts of a gene is derived from different sources (e.g. Agorram, 2010; Burian, 2013), the way the information was used to build the resource is the same. Here, the common misconceptions were adopted as a framework to create the resource. The content was selected to match the scaffolding. In this case, the content was selected to present the concept of a gene based on the historical model of a gene proposed by Gericke and Hargberg, (2007) and its updated version (Smith and Adkison, 2010).

All in all, the findings from the resource developmental process showed that it is possible to utilise the two ways described above to create educational resources.

7.1.2. The potential of predicting students' misconceptions from published common misconceptions

This section responded research question 2: What are university students' existing perceptions of the basic concepts of genetics*?*

The findings from the investigation of the existing misconceptions of meiosis, Mendelian inheritance, and the concept of a gene (see detailed discussion in sections 4.6, 5.5 and 6.6, respectively) showed that Indonesian and UK participants of this study shared common misconceptions used to inform the design and the construction process of targeted resources. This was evidenced by the low number of correct responses in the concept inventory test (or its equivalent) which indicated students having specific misconceptions in each concept in question.

In some cases, further analysis also showed that Indonesian participants possess further misconceptions which were not revealed in published common misconceptions. For example, several Indonesian participants misconceived gametes as any cell involved in meiosis, including cells at the beginning of prophase 1 (see further discussion in section 4.4 and 5.3). In similar cases around understanding meiosis, there was evidence that Indonesian students thought that in gametes maternal and paternal chromosomes would combine into one duplicated chromosome. Although the findings showed the participants other individual misconceptions idea, the basis for the misconceptions generally followed from the roots of common misconceptions in misunderstanding the concepts of gametes and haploid cells. This is possible because students have their own way of constructing the knowledge, which lead to many possibilities of misinterpreting the concepts that are being taught (Gooding & Metz, 2011; Tyson, 1996). Thus, by

reviewing that individual misconceptions have the same source as the common misconceptions, this indicates that the published common misconceptions serve as a good predictor of misconceptions in the classroom. The findings also confirmed the view that common misconceptions are widespread (Fisher and Moody, 2000).

Reviewing the parallels between published common misconceptions and the participants' misconceptions in this study, reveals that participants also shared similar misconceptions with students in secondary schools (equivalent to middle school, age 13-15, and high school, age 16-18) in different countries. An example of this fact was taken from students' pre-existing conceptions of gene in the study of reconceptualising the gene concept (Chapter 6). Several Indonesian participants had conceptualised a gene as a trait or as trait bearing particles (see section 6.6) which was consistent with the conceptualisation of gene i secondary school students in the UK (age 13-15) (Lewis and Wood-Robinson, 2000) or second year primary school students in Australia (age 7-11) (Venville, Grady and Donovan, 2007). Parallel to that, the hybrid concept of defining a gene based on the molecular model but representing gamete using classical model seen with the UK participants in this study is similar to those experienced by student teachers in Turkey (Dikmenli, 2011).

This finding supports the plausibility of using information from published common misconceptions to predict the students' misconceptions in class. This implies the likelihood of anticipating students' misconceptions based on the published typical misconceptions for a topic. Consistently, it also supports the idea that teachers/instructors are able to use this information to tackle students' misconceptions in their class, particularly by providing related resources before actually starting a lesson.

7.1.3 The ways targeted teaching resources alter students' misconceptions

This section responds to research question 3: In what ways do the targeted educational resources modify university students' misconceptions of basic concepts in genetics?

This research question is divided into three subsections. Each subsection has a different focus in answering research question 3. The discussion for this section will begin by discussing the overall findings from each of its three sub research questions.

a) The targeted resources promoted various concept changes in participants

This subsection responds to research question 3.1: What misconceptions are altered after use of the targeted resources?

Three targeted educational resources have been developed to address specific common misconceptions. As discussed in section 4.2, 5.2, and 6.2, the three resources had different formats which were chosen as integral part of the strategy in addressing common misconceptions. It was expected that the three educational resources would effectively challenge and change students' misconceptions. A summary of changes for each of the targeted common misconceptions in each topic is presented in Table 7.2.

Based on all cases, the different changes experienced by students were highly likely to be related to the need to revise the subordinate (supporting) concepts to make substantial changes. Students with severe misconceptions about a topic (e.g. such as indicated by the low number of correct scores in answering pre-MCI) tended to focus their attention on revising the subordinate concepts rather than understanding the whole message of the resource. This is likely to be the result of selective attention (Eysenck and Kane, 2000) which limited the capacity of the students' working memory (Chu and Reid, 2012). Students also applied the same method in revising their concept of a gene, which was indicated by some participants' revised representation of their current model of a gene and did not propose the advancing concepts in terms of historical progress concept of a gene.

In conclusion, all three educational resources, to some extent, had helped students to change their previous incorrect conceptions. However, the level of the successful changes was varied due to the need to revise subordinate concepts before modifying the conception of meiosis, Mendelian inheritance, or the concept of a gene as targeted in this study.

b) Elements of targeted resources that contribute to students' conceptual change

This subsection presents the overall findings in response to research question 3.2: What elements of the targeted resources contribute to the change?

Each educational resource was designed to advance students' concept changes in the topic that they previously misconceived. The content and format of the resources were specifically designed and developed to obtain this purpose. However, each resource strategy had a different impact on students' conceptual change as shown in Table 7.3.

Table 7. 2 A summary of the concept changes stimulated by the use of targeted educational resources

Evaluation of resources involved different groups of participants. "N/A" on the participant column, showed the cohort is not a group of participants for that specific educational resource evaluation. The first and second cycle showed which stages in the resource development that the cohorts were involved. Number following each participant showed the number of participants experiencing the changes. The number of changes is calculated from students who initially have the misconceptions [from triangulated data of test and interview].

Resources name [format]	**Targeted common misconceptions**	**Changes**				
		Description of changes	**Number of participants for group …**			
			IND-1	**IND-2**	**IND-3**	**UK**
Meiosis video [Animated video] & Follow-up simulation activity*	• Subordinate concepts of meiosis: o Ploidy o Structure of chromosome • Process/stages of meiosis o Events of meiosis stages o Genetic diversity		**1st cycle (n=17)**	**2nd cycle (n=19)**	-	**2nd cycle (n=2)**
		Differentiating haploid from diploid	0	3	N/A	0
		Differentiating sister chromatids vs homologous pairs	2	5	N/A	0
		Recognising what counts as a chromosome	2	2	N/A	1
		Recognising changes on chromosome behaviour per stage	3	6	N/A	0
		Recognising contribution of crossing over and random assortment on the generation of genetic diversity	0	1	N/A	1
Inheritance cards activity [card activity]	• A link between meiosis and Mendelian inheritance		-	**1st cycle** (n=17)	-	**1st cycle (n=2)**
		Realising link between meiosis and Mendelian crosses	N/A	2	N/A	2
		Revision of concept of meiosis	N/A	4	N/A	0
		Revision concept of autosome/sex chromosome	N/A	3	N/A	1
		Revision on the structure of allele-chromosome	N/A	7	N/A	1
The gene concept booklet [booklet]	• A limited understanding of a gene • A hybrid concept of a gene		-	**1st cycle** (n=21)	**2nd cycle** (n=9)	**1st cycle** (n=2)
		Advancing concept of the gene	N/A	21	7	2
		Non-hybrid concept of the gene	N/A	7	7	2

Notes: *Follow-up simulation activity was introduced with two groups (IND-2 and UK)

The concept of a gene booklet encourages the higher frequency of students having a concept change. The effectiveness of this resource was due to its simple design and focusing task (see Table 7.3). The pre-test was effectively used to elicit students' ideas of a gene before they began to compare their idea with various concepts of a gene presented in historical manner in the booklet. The pre-test acted as the first step of concept change; the individual elicitation of students' ideas for concept changes (Fisher and Moody, 2000). Many students were motivated to change their outdated model of a gene by comparing their new understanding of gene from the content presented in the booklet with their pre-test. The possibility of a change was also increased by having correct supporting concepts to achieve the change, for example many students understood a gene is a sequence of DNA.

Among the three educational resources developed in this study, the animated video illustrating meiosis was the resource with the most heavy-loaded content. Although it was designed to have a simple format (as a video), it contained different strategies to deal with the most common anticipated misconceptions in meiosis (see Table 7.3). The selected strategies were considered working by observing a number of students who had changed their misconceptions by watching the video. Since misconceptions are resistant to change (Fisher & Moody, 2000), even a small number of changes signified an effective working strategy in dealing with misconceptions of meiosis. To improve the effectiveness of the video, an additional follow-up activity was designed to focus students in searching for useful information on the video regards to concepts they considered as difficult. The introduction of this strategy improved the number of students who changed their misconceptions, particularly in the understanding of simultaneous concepts of meiosis.

The inheritance cards activity was designed to explicitly visualise the relationship between Mendelian inheritance and meiosis (see Table 7.3). However, a very limited number of students realised this connection (see Table 7.2), the majority of students changed concepts supporting the Mendelian inheritance-meiosis relationship (e.g. revision in the concept of meiosis). This was due to the visualisation of the concept of meiosis and autosome/sex chromosome in this resource.

Table 7. 3 A summary of the strategies of each targeted educational resource in stimulating concept change.

Resources name	Targeted common misconceptions	Strategies
Video resource illustrating meiosis & Follow-up simulation activity*	• Subordinate concepts of meiosis: o Ploidy o Structure of chromosome • Process/stages of meiosis o Events of meiosis stages • Replication • Meiosis o Genetic diversity • Contributing factor • The process	Visualise haploid and diploid cell containing single and duplicated chromosome Visualise structure of sister chromatids, followed up by homologous chromosomes Counting number of chromosomes: single and duplicated (before and after replication) Visualise the time of event related to cell cycle Visualise the complete mechanism of meiosis, equipped with the additional cue of event on each stage and ploidy of the daughter cells ***(****e.g. meiosis 1* - homologous pairing and crossing over at prophase 1, continued with the lining up the pairs on the metaphase plate, the segregation of pairs and the grouping of chromosomes on two cell poles. Visualise two factors of meiosis contributing on the generation of genetic diversity (***e.g. Random assortmennt)*** Visualise combination probabilities of paternal and maternal chromosomes in daughter cells showing how the combination of paternal and maternal chromosomes from parents to the next generation through meiosis
Inheritance cards activity	• A link between meiosis and Mendelian inheritance	Visualise how meiosis produced variants of gametes (which related to prediction of gamete on Punnett square) Determining the location (locus) of alleles on autosome or sex chromosome Labelling alleles to determine the genotype of gametes
The gene concept booklet	• A limited understanding of a gene • A hybrid concept of a gene	Presents various concept of a gene in a historical order, completing with pictorial representational of the model

Notes: *Follow-up simulation activity was introduced only with two groups (IND-2 and UK)

c) Students perception to their learning experiences using targeted resources

This subsection presents the overall findings in response to research question 3.3: How do university students perceive their learning experience with the targeted resources?

Students' perceptions of the resource were invaluable in the development of resources in this study.it is students who will take advantage of the targeted resources to facilitate their construction of knowledge, according to the constructivist learning approach (Bodner, 1986). Though students expressed different points of engagement with the resource, the reason for choosing these points was viewing a concept visualisation that they did not find in other learning resources.

The Indonesian cohort (IND-1, IND-2) was attracted to the visualization of stages of chromosome behavior in the meiosis video, due to the fact that it was provided in their mother tongue (Indonesian) language. All participants groups (IND-1, IND-2, and UK) thought the most useful part of the video was the section dedicated to visualising the subordinate concepts of meiosis (ploidy and structure of chromosome) which helped them in gaining new understanding, which they claimed was not the focus of other meiosis videos. Carrying out the simulation activity following viewing of the educational video was considered more engaging for the UK students, as the designed activity was new for them, while the Indonesian students (both IND-1 and IND-2) were not fully attracted because they needed to spend more time understanding the activity instruction.

The inheritance cards activity had a different impact on students' interest. For some Indonesian (IND-2) students the whole activity was interesting since they were challenged, while for other students, labelling alleles was the most inspiring aspect. Students thought the inheritance cards gave them a better chance of observing how random distribution of meiosis takes place, and how gametes are produced, which they did not find using other resources discussing meiosis. All groups (IND-2 and UK) agreed that inheritance cards helped them to visualise autosome and gonosome (sex chromosome) better.

The gene concept booklet was considered interesting by most students (IND-2, IND-3, and UK) due to its presentation of historical concepts of a gene. The task was designed to ask them to reflect on their idea of a gene whilst they were reading the content of the booklet; this task effectively stimulated the students to rethink their

concept of a gene. Students liked the idea of finding new information about genes while they were reading the booklet.

When IND-2 and UK students were asked to reflect on which of the targeted educational resources they enjoyed the most, the majority (47%) chose the concept of a gene the booklet as their favourite. Interestingly, despite the different choices of their favourite resource, the reason behind the choice was similar. Students preferred a specific resource because they perceived they gained a better understanding of the topic depicted by the resource.

In summary, students' preferences for specific targeted resources developed in this study were influenced by their perception of obtaining meaningful learning from engaging with the activity and the resource. This suggests that for this group of students, possibly representing the general undergraduate student population, there is a preference for the teaching resources which gave them an impression of achieving a new understanding of a topic over simply finding enjoyment in carrying out the activity.

7.1.4 The advantage of including comparative cases to evaluate the effectivity of targeted educational resources

This section responds to research question 4: Are there any differences in the way university students in Indonesia and the United Kingdom perceive the benefits of the targeted educational resources?

The comparative cases of the UK and Indonesia provide an initial insight of the advantages of the development of teaching resources using information from common misconceptions. The commonness of the misconceptions regards to topics which was developed here was discovered among students in both Indonesian and UK cases. When learning the concept of meiosis, students in all groups that watched the video (IND-1, IND-2, UK) experienced the same difficulties in understanding subordinate concepts of meiosis and showed signs of confusion between meiosis and mitosis. However, the Indonesian students (IND-1 and IND-2) had further misconceptions with the concept of chromosomes and their understanding of the term 'gametes', both of which were not found in the counterpart case. For learning concept of inheritance using inheritance cards, students in the IND-2 and UK groups experienced similar confusion in understanding chromosomal pairing between sex chromosome (XY). Another misconception related to the production of gametes was found in the IND-2 cohort,

which led to further erroneous ideas of allelic segregation in the Mendelian inheritance cross. Although students from Indonesia (IND-2, IND-3) and the UK started with a different idea of a gene, a more classical idea for the former cohort and a more molecular idea for the latter, a hybrid conception of gene, which is a sign of confusion or misconceptions of a gene (Dos Santos, Joaquim and El-Hani, 2012),was found in both countries.

This study also provided insight into the way students gain benefit from learning topics using targeted resources. Indonesian (IND-2) and UK students had different preferences when watching the meiosis video and in performing the follow-up simulation activity. The latter (UK) preferred doing the activity over watching the video. These students perceived the activity to be a useful hands-on experience considered more important in enhancing their understanding of meiosis. However, participants in all groups watching the video (IND-1, IND-2, UK) agreed that it was useful for revising or justifying their understanding of meiosis, particularly the first part of the video where all terminology related to the subordinate concepts of meiosis was explained. Furthermore, when conducting the inheritance cards activity, UK students were more familiar with the visualisation of randomisation of independent assortment of chromosomes using coins. This reduced their cognitive process required to understanding the representation, known as the *germaine* cognitive load (Cook, 2007). Therefore, students in the UK case had a better chance of observing the mechanism of meiosis and how it relates to Mendelian inheritance. Meanwhile, despite the differences of the initial conception of a gene, Indonesian (IND-2, IND-3) and UK students both experienced a revision of their concept of a gene which was stimulated by the designated task that required them to reflect on their idea of a gene.

The similar results from both of these cases of Indonesian and UK student evaluating targeted resources provide further justification for the possibility of predicting common misconceptions related to specific basic genetic concepts. Furthermore, the similarities and differences in the way the targeted educational resources modified students' concepts of the topic of interest provided additional information on the strengths and weaknesses of each resource. Accordingly, this information was then used to develop the effective use of the resources in the next trial cycle.

7.2 Limitations of research

7.2.1 Participants

The comparative part in this study was intended to find the differences and similarities in how students benefit from the targeted educational resources in two different settings (Indonesia and the UK). However, the number of participants in the UK cohort was very small, which limited a meaningful comparison. There are two possible reasons for the low numbers of UK participants:

i. Timing of recruitment: The study was conducted near the end of term, when students were busy with exams.
ii. Students' interest for the study: The purpose of study may not have directly connected with the students' interest in the UK. The UK participants were recruited from the biology and biomedical undergraduate programme, while the Indonesian participants were recruited from the biology education programme (biology student teachers).

Although this study involved students from two different countries (Indonesia and the United Kingdom), the participants were recruited from only one university in each country (Universitas Tanjungpura, Indonesia and University of Leicester, UK). Therefore, the findings may not reflect the general conclusion for students in the two countries. The IND and UK case in this study are merely terms which refer to the specific cohort of students.

7.2.2 Time constraint

Evaluation data were collected in an informal setting (out of formal lecture time) during term time. An obstacle in adopting this setting was in finding a time when all students could join in the evaluation (in IND-1 and IND-2 case). Although there were two sessions provided for each resource evaluation, there were students who could not fit either into their schedule. This affected the number of participants involved in each resource evaluation. Due to the need of triangulated data, data from participants who did not participate in a complete set of data collection (e.g. participating in the test but not in the interview) were not included in the analysis. This made a variation in the number of participants included in the analysis of the resource evaluation.

7.2.3 Researcher bias

Findings in qualitative research depend mainly on the interpretation of lots of data from different sources. In this study the researcher interpreted all the data. Although validation of interpreted data was sought through conducting data triangulation, there is still a possibility of individual bias in the interpretation of data.

7.3 Implications of the research and future studies

The findings of this research have implications for the practice of teaching genetics, and biology teaching in general, and methods for research in science education.

7.3.1 Implications for the teaching of genetics

This study has clearly shown the need to give more attention to teaching basic genetics concepts. There is a general assumption that all students who enter undergraduate programmes will be equipped with basic concepts relevant to their subject of study. However, through this study it was shown that students still experience misconceptions in basic genetics concepts. The similarity of the misconceptions with those found in secondary school students, demonstrated that this problem could not be underestimated and needs to be resolved before they continue learning the more complex concept of genetics.

This study also shows that many students still struggle to understand supporting (subordinate) concepts as part of understanding the basic genetics concepts. It is therefore important that an instructor pays substantial attention and takes sufficient time to teach these important key concepts.

In deciding which concepts are important to highlight or emphasise when teaching genetics, concepts which are demonstrated as having common misconceptions (as presented in many published articles) could be fundamental when anticipating similar misconceptions in the classroom. In addition, information on common misconceptions could also be used to prepare teaching/learning resources before instruction takes place, as demonstrated in this study. These findings could therefore also be relevant teaching for other biology subjects, and science subjects in general.

7.3.2 Implications for alternative methods in developing educational resources

This thesis had adopted an action research approach to developing the targeted educational resources. The four stages of action research in developing resources were modified from the original stages of action research proposed by (Lewin, 1946). Possible modifications from the original stages of action research were shown by Cohen *et al*., (2011). As long as the original idea of doing research while performing action or researching the implication of an action is preserved, changes are possible (Stringer, 2014; McNiff & Whitehead, 2011). Accordingly, this study has successfully demonstrated the plausibility of developing targeted teaching/learning resources through the modified four stages of action research, (1) design, (2) create, (3) evaluate and (4) reflect (see Figure 7.1).

Developing learning materials for instruction has been demonstrated using different methods, for example developmental research method proposed by (Richey, Klein and Nelson, 2004; Richey and Klein, 2005) or the ADDIE (analysis, design, develop, implement and evaluate) in the instructional system design demonstrated by (Shibley *et al*, 2011; Gagné *et al.*, 2005). However, both approaches are more applicable in the designing and evaluating of instructional systems, whereas the resource development was just part the instructions. The modified action research approach also served the ultimate goal in making the instructional instruments (including resources) available for use in a wider context.

By adopting an action research approach in developing educational resources it has be shown that the production of teaching/learning material (resources) does not always have to be mass production, as demonstrated by the philosophy of classroom action research (Cohen *et al.*, 2011; Lichtman, 2000). Similarly, the success of the application of action research in developing targeted educational resources in this study suggests that a teacher/instructor in genetics or other science subjects may create their teaching resources for their own classroom. The performance of research in cycles suggests the plausibility of carrying out continuous revision of the resources while they conduct their teaching.

Beyond the local context and application of action research, the prospect of the general application of teaching/learning resources could be proposed by embedding the comparative cases into the evaluation stage. The comparison of cases is not normally part of the action research approach (Stringer, 2014; Cohen et al., 2011). In this study,

the comparative case acted as additional data to evaluate the effectiveness of targeted educational resources which were designed based on the common misconceptions of the topics of interest. A novel method for developing teaching/learning resources using an action research approach is presented in Figure 7.1.

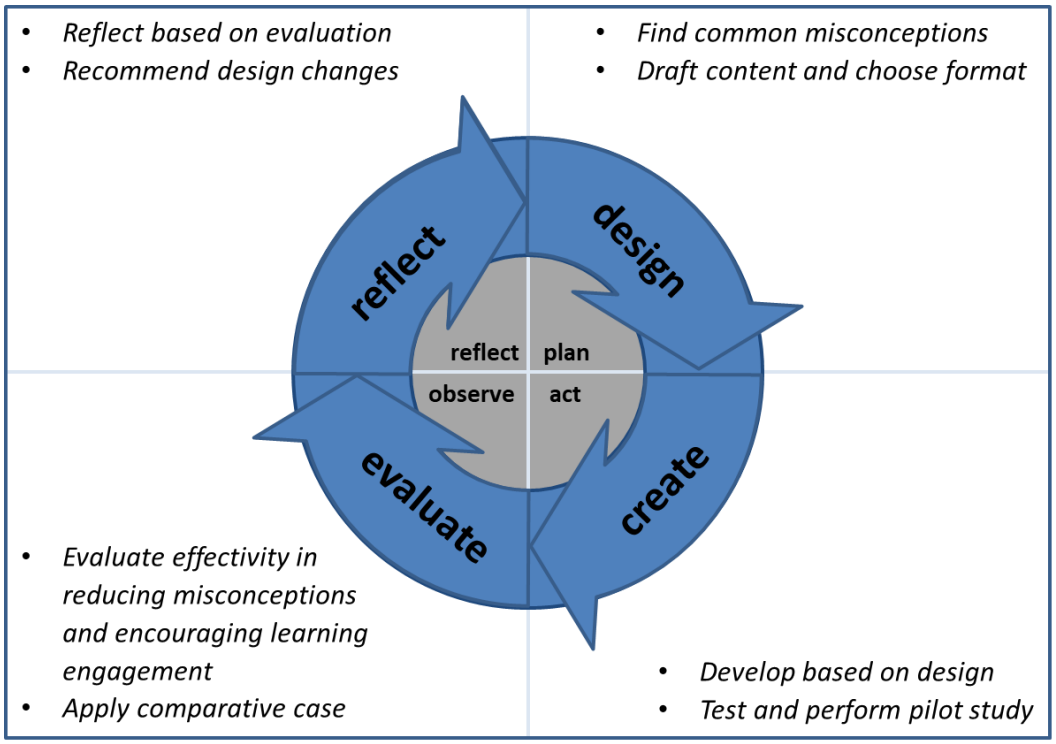


Figure 7. 1 A novel method for developing teaching/learning resources using an action research approach. *The grey coloured zone (inner circle) showed the original stages of action research (Cohen et al., 2011; Stringer, 2004). The blue arrows in the middle ring show the modified stages used in developing the educational resources. The cycle started with the design stage (top right) and continues clockwise. The box areas show the activities for each stage of resource development.*

7.4 Recommendations and future studies

In reproducing a similar study with students in different countries or at a different level of education, some considerations regarding the data analysis methods used should be taken into account. Despite the fact that data triangulation from two (or more) data sources (e.g. test and interview) provides a comprehensive understanding of the students' conceptual understanding and perception, this approach is very time-consuming. This study has shown it is possible to gain similar insights into students' misconceptions by just using interviews. Of the three data sources used in this study, the interview was the richest by far, and clearly revealing any misconceptions.

In addition, this study has shown that university students' misconceptions are similar to the common misconceptions published worldwide, including those revealed from a different educational level, secondary school. This similarity suggests that university students' misconceptions may be perpetuated by their misconceptions at the previous level of education. This was also revealed during the interviews where students included what they had learned in the secondary school or college to explain their existing understanding of the basic concepts of genetics. Reflecting from the resistance of the misconceptions and the limitations on addressing university students' misconceptions in this study, it is far more important to prevent misconceptions before they occur. Therefore, it is necessary to implement studies on the causes of misconceptions for basic concepts of genetics at secondary school and college level. This could then be followed up by an attempt to address these specific misconceptions by developing corresponding educational resources using the modified action research approach, as recommended in this study. Accordingly, a study to try and tackle the sources of misconceptions could also involve the use of the three educational resources developed in this study to inform the possibility of using these resources to prevent as well as tackle misconceptions.

Finally, the very low proportion of Indonesian students having a solid understanding of basic concepts of genetics, such as meiosis, Mendelian inheritance, and the concept of a gene, as identified in this study, suggest that serious problems in grasping the core concepts of genetics may be widespread in Indonesia. Therefore, extensive research is required to reveal and improve Indonesian university students' level of understanding of the basic concepts of genetics, to be able to improve the quality of genetics education in particular, or biology and science in general, in Indonesia.

7.5 Final remarks

Despite some limitations of the study, this research showed that the three educational resources had helped participating students to improve their understanding on the targeted fundamental concepts. The effectiveness of the educational resources on improving misconceptions was on the initiation of self-awareness to the limitations of their existing understanding of fundamental concepts in genetics which is vital to encourage them to change their views. This study also shows the possibility of creating

the educational resources which specifically tackled incorrect conceptions based on the common published misconceptions. Lastly, this research also proved the feasibility of adopting the modified action research steps in creating the educational resources.

Appendices-A

This section presents all appendices related to Chapter 3 of the main body of thesis.

A-1. Instrument for data collection - Concept test: MCI (English version)

The 17 MCI questions used in this study (English version) were developed by Kalas *et al*., (2013) and were used under an embargo agreement with the authors of the paper. Therefore, these questions are not published here, but are available on request to the author of this thesis.

A-2. Instrument for data collection - Concept test: MCI (Indonesian version)

The 17 MCI questions used in this study (Indonesian version) were translated by the author from the original MCI questions developed by Kalas *et al*., (2013) and were used under an embargo agreement with the authors of the paper. Therefore, these questions are not published here, but are available on request to the author of this thesis.

A-3. Instrument for data collection – Concept test: GCA (selected number, English version)

The six number of GCA questions used in this study (English version) were part of the 25 GCA questions developed by (Smith, Michelle K., Wood and Knight, 2008) and were used under an embargo agreement with the authors of the paper. Therefore, these questions were not published here, but are available on request to the author of this thesis.

A-4. Instrument for data collection - Concept test: GCA (selected number, Indonesian version)

The six number of GCA questions used in this study (Indonesian version) were translated by the author from the original 25 GCA questions developed by (Smith, Michelle K., Wood and Knight, 2008) and were used under an embargo agreement with the authors of the paper. Therefore, these questions were not published here, but are available on request to the author of this thesis.

A-5. Instrument for data collection - Concept test: Test of the concept of the gene (English version)

My Definition of gene

What comes up in your mind when you hear this word: "gene"? How would you define it?

Write down your own definition of gene in the space provided. Support your narration with picture(s) or diagram(s) of what you visualised as "gene".

(You may, for example, draw a structure of gene, or its location related to other molecules, or any verbal diagram with additional notes which show the representation of gene in your mind)

What is your definition of "GENE"? (Write as detail as possible)

How do you visualise GENE?

A-6. Instrument for data collection - Concept test: Test of the concept of the gene (Indonesian version)

Definisi saya tentang gen

Apa yang tergambar saat Saudara mendengar istilah "gen"?

Tuliskan definisi pribadi Saudara tentang gen pada kolom berikut. Dukunglah definisi tersebut dengan gambar atau diagram (misalnya lokasi relatif gen, atau suatu peta konsep sederhana) yang dapat memvisualisasikan pemahaman Saudara tentang gen.

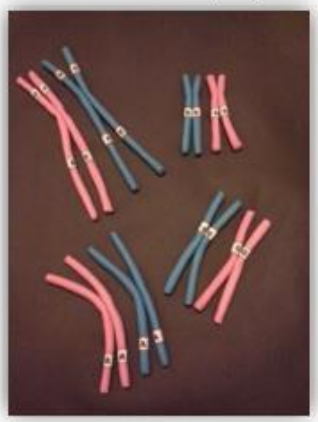
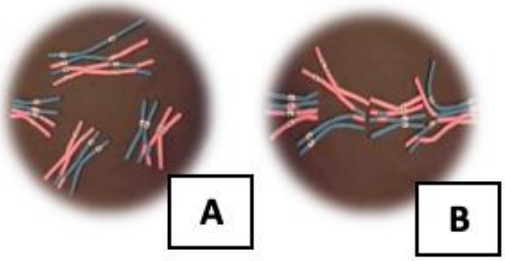
Apa definisi Saudara tentang "GEN"? (Tuliskan sedetail mungkin)

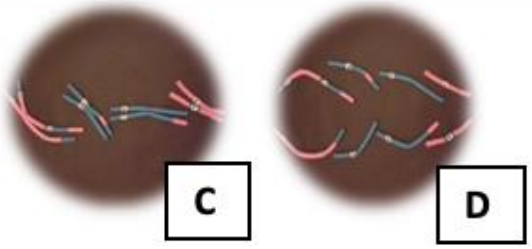
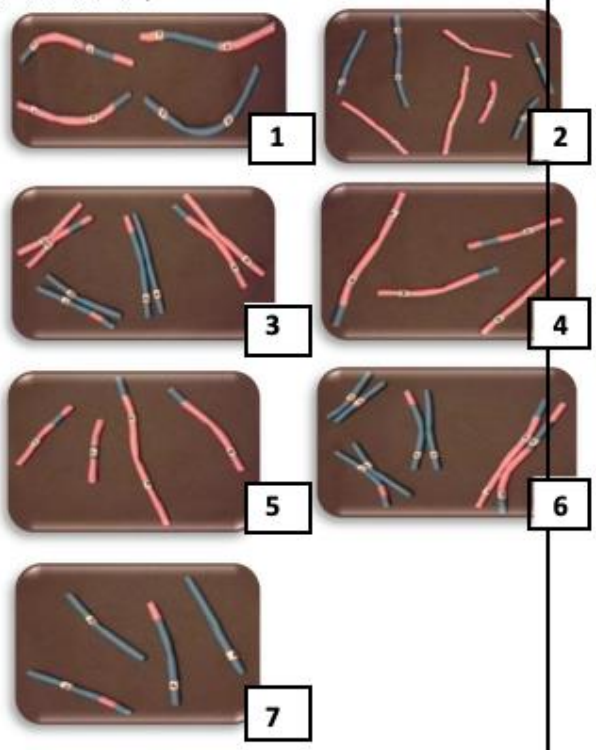
Bagaimana gambaran visual dari "GEN" tersebut?

A-7. Instrument for data collection - interview guidelines of a semi-structured interview: concept of meiosis, Mendelian inheritance, and concept of a gene (English version)

Interview guidelines: Video of Meiosis

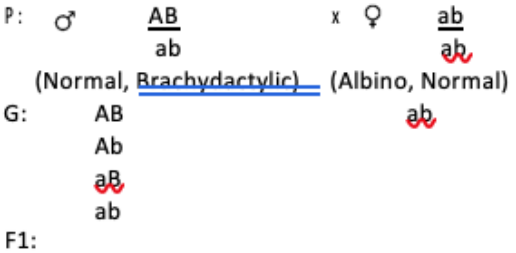
Purpose of research : to evaluate how video improve students' understanding of meiosis
Purpose of interview : to evaluate students' understanding of meiosis and their perception to the video
Elicitation technique : pictures of model of chromosomes (taken from MCT)
Length : 30 minutes

Main topics	Key Questions	Prompts
Concept	How would you describe your learning experience of meiosis using the video?	• Concept of meiosis • Events of meiosis shown in the video
Concept	Suppose this is a model of a cell which shows its chromosomes. It prepares to undergo meiosis. What kind of information can you get from this cell? 	• Number of chromosomes (somatic and gamete) • Which structure are (sister) chromatids • Which structure are homologous pairs • Number of DNA molecules • Ploidy of cell
Concept	If the cell in picture 1 (previous) undergoes meiosis, what would be happen to the cell which make it show a condition as potrayed in the second picture? (one of A/B/C/D) 	• Events lead to stage of meiosis

		
Concept	Let's suppose the cell have been completed normal meiosis (no non-disjunction) and eventually produced daughter cells. I will show you some pictures of a cell. Can you explain whether the picture of a cell I show you is possible as one of the daughter cells? (1/2/3/4/5/6/7) 	• Concept of alleles/genes • Concept of ploidy
Response	In what ways the video helped you to understand meiosis concept?	• Which part is the most engaging? • Which part is the least favorite?
Response	What will you do to improve this video to support you in learning concept of meiosis?	• Technical aspects • Content presentation
Response	How the following task-activity help you to understand concept of meiosis?	• Which part is the most engaging and the least one? • Kind of difficulties in doing the activity

Interview guidelines: The Inheritance Card Activity

Purpose of research : to evaluate how cards activity improve students' understanding of Mendelian inheritance
Purpose of interview : to evaluate students' understanding of Mendelian inheritance and their perception to the cards' activity
Elicitation technique : diagram
Length : 25 minutes

Main topics	Key Questions	Prompts
Concept	Could you describe what you learnt from doing inheritance cards activity	• Concept of single Mendelian inheritance • Concept of patterns of inheritance
Concept	If an albino woman married to a man who does not suffer from albinism, what is their probability of having a child who suffer to albinism? Is it always 25%? (optional)	• Probability
Concept	I will show you a card with a diagram of crossing.  ♀ \ ♂ | AB | Ab | aB | Ab ab | AB/ab (Normal, Brachydactylic) | Ab/ab (Normal, Normal) | aB/ab (Albino, Brachydactylic) | ab/ab (Albino, Normal) Do you think that this crossing represents a single gene inheritance? Why? What patterns of inheritance showed on the diagram?	• Position in diagram which show meiosis • Location of gene (autosomal or sex chromosome) • Pattern (dominant or recessive trait)
Response	In what ways the card of inheritance helped you to understand Mendelian inheritance concept?	• Which part is the most engaging? • Which part is the least favorite or difficult
Response	What will you do to improve this cards activity in the future to support you learning concept of Mendelian inheritance?	• Technical aspects • Content presentation

Interview guidelines: Concept of Gene

Purpose of research : to evaluate how booklet improve students' understanding to the concept of a gene
Purpose of interview : to evaluate students' concept of a gene and their perception to the booklet
Elicitation technique : -
Length : 20 minutes

Main topics	Key Questions	Prompts
Concept	Could you describe what you learnt from reading the booklet of the concept of a gene?	• Concept of a gene
Concept	Can you describe your concept of a gene prior reading the booklet? Is there any different from your current concept of a gene? (if it is) why do you change your concept?	• Any concept changes
Response	In what ways the booklet helped you to understand concept of a gene?	• Which part is the most engaging? • Which part is the least favorite or difficult
Response	What will you do to improve booklet to support you more in learning concept of a gene?	• Technical aspects • Content presentation

A-8. Instrument for data collection - interview guidelines of a semi-structured interview: concept of meiosis, Mendelian inheritance, and concept of a gene (Indonesian version)

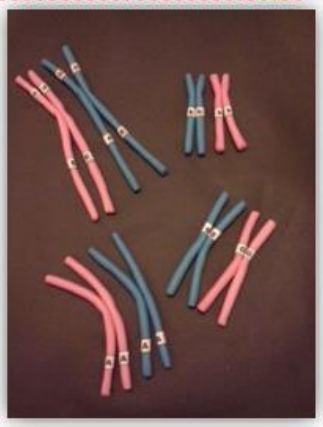
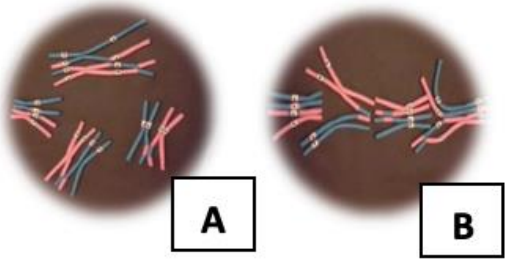
Panduan interview: Video Meiosis

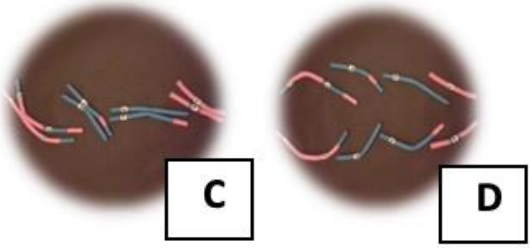
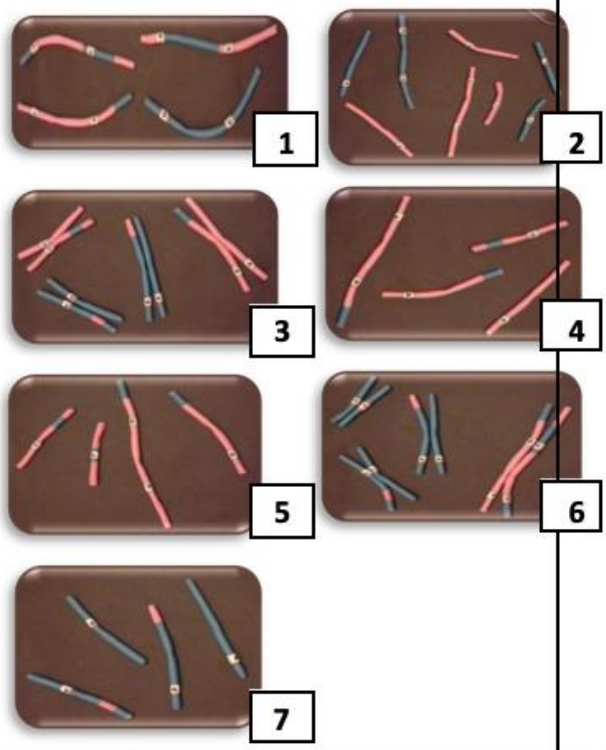
Tujuan riset : mengevaluasi bagaimana video meningkatkan pemahaman mahasiswa tentang meiosis

Tujuan interview : Mengevaluasi pemahaman mahasiswa tentang meiosis dan persensi mereka terhadap video

Teknik diskusi : gambar model kromosom (diambil dari MCT)

Waktu : 30 minutes

Topik	Pertanyaan kunci	Arahan
Konsep	Ceritakan pengalamanmu belajar tentang meiosis menggunakan video. Apa yang kamu dapatkan?	• Pengertian meiosis • Tampilan konsep meiosis di video
Konsep	Misalkan ini adalah suatu model sel yang menunjukkan kromosomnya. Sel ini sedang bersiap melakukan meiosis. Informasi apa saja yang dapat kamu ceritakan tentang gambaran sel ini? 	• Jumlah kromosom (sel somatic dan gamet) • Struktur mana yang disebut sebagai kromatid bersaudara • Truktur mana yang disebut sebagai pasangan homolog • Jumlah molekul DNA • Ploidi sel
Konsep	Jika sel pada gambar 1 (sebelum ini) mengalami meiosis, apa yang akan terjadi pada sel sehingga dia memiliki tampilan seperti pada gambar 2? (salah satu dari A/B/C/D) 	• Peristiwa yang menyebabkan terjadinya tahapan tertentu meiosis

		
Konsep	Misalkan sel yang sama telah menyelesaikan pembelahan meiosis secara normal (tidak ada gagal berpisah) dan akhirnya memproduksi sel anakan. Saya akan menunjukkan beberapa gambar sel. Bisakah kamu jelaskan apakah gambar sel yang saya tunjukkan tersebut mungkin atau tidak sebagai salah satu sel anakannya? (1/2/3/4/5/6/7) 	• Konsep alel/gen • Konsep ploidi
Respon	Dengan cara bagaimana video menolongmu memahami konsep meiosis?	• Bagian mana yang paling menarik • bagaimana yang paling tidak menarik
Respon	Apa yang akan kamu lakukan untuk memperbaiki video supaya mendukungmu mempelajari meiosis?	• Teknis • Konten
Respon	Bagaimana aktivitas yang menyertai video membantu kamu dalam memahami meiosis?	• Bagian mana yang paling menarik dan yang tidak • Kesulitan apa yang didapatkan pada saat mengerjakannya

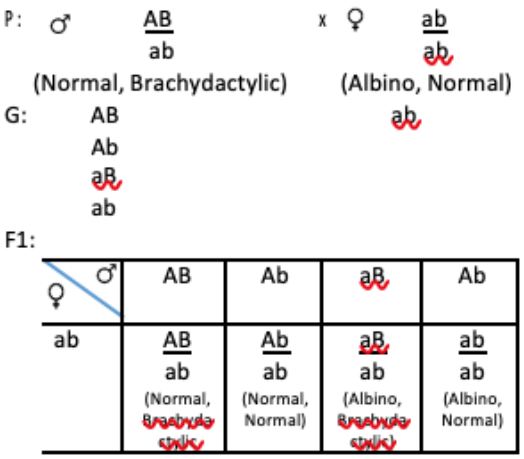
Panduan interview: Kartu inheritance

Tujuan riset : mengevaluasi bagaimana aktivitas dengan kartu inheritance meningkatkan pemahaman mahasiswa tentang Mendelian inheritance

Tujuan interview : Mengevaluasi pemahaman mahasiswa tentang Mendelian inheritance dan persepsi mereka terhadap kartu inheritance

Teknik diskusi : diagram

Waktu : 25 minutes

Main topics	Key Questions	Prompts
Konsep	Bisakah kamu ceritakan apa yang kamu pelajari menggunakan aktivitas dengan kartu inheritance?	• Konsep Mendelian inheritance • Konsep pola pewarisan sifat
Konsep	Jika seorang wanita albino menikah dengan seorang laki-laki yang tidak menderita albinisme, bagaimana kemungkinan mereka memiliki anak yang menderita albino? Apakah selalu 25%? (optional)	• Probabilitas
Konsep	Saya akan menunjukkan padamu kartu dengan diagram persilangan.  Apakah menurutmu persilangan ini mengikuti pola pewarisan Mendelian inheritance? Mengapa? Pola Pewarisan Mendel tipe apa yang tampak?	• Posisi pada diagram yang menunjukkan meiosis • Lokasi gen (autosomal or kromosom sex) • Pola (dominan atau sifat resesif)
Respon	Dengan cara apa melakukan aktivitas dengan kartu inheritance menolongmu mempelajari Mendelian inheritance?	• Bagian mana yang paling menarik dan bagian mana yang tidak menarik • Bagian yang sulit
Respon	Apa yang akan kamu lakukan untuk meningkatkan fungsi kartu ini dalam membantumu mempelajari konsep Mendelian inheritance lebih baik lagi?	• Teknis • Konten

Panduan interview: Konsep gen

Tujuan riset : mengevaluasi bagaimana penggunaan booklet meningkatkan pemahaman mahasiswa tentang konsep gen

Tujuan interview : mengevaluasi pemahaman mahasiswa tentang konsep gen dan persepsi mereka terhadap booklet

Teknik diskusi : -

Waktu : 20 minutes

Topik	Pertanyaan kunci	Arahan
Konsep	Bisakah kamu ceritakan apa yang kamu pelajari pada saat membaca buku tentang konsep gen?	• Konsep gen
Konsep	Bisakah kamu ceritakan tentang konsep gen yang kamu miliki awalnya? Apakah ada perbedaannya dengan konsep gen kamu sekarang ini?	• Ada perubahan konsep
Respon	Dengan cara apa booklet membantumu untuk memahami tentang konsep gen?	• Bagian mana yang paling menarik • Bagian mana yang paling tidak menarik dan sulit
Respon	Apa yang akan kamu lakukan untuk meningkatkan fungsi booklet untuk lebih mendukungmu dalam mempelajari konsep gen?	• Teknis • Konten

Appendices-B

This section presents all appendices related to Chapter 4 in the main body of thesis.

B-1. Educational resource: the meiosis video (English version).

A complete sequence of the video is provided on Youtube. Access link: https://youtu.be/S9E8e1m2Z6U

B-2. Educational resource: the meiosis video (Indonesian version).

A complete sequence of the video is provided on Youtube. Access link: https://youtu.be/7uv-xEP8dFQ

B-3. Raw data of pre and post MCI test (IND-1 and IND-2) and post MCI test (UK)

The correct answers for the 17 MCI questions used in this study were provided by Kalas *et al*., (2013) and were used under an embargo agreement with the authors of the paper. Therefore, the raw data of the pre and post-test IND-1 and IND-2 and post MCI test UK are not published here, as they are part of the embargo agreement, but are available on request to the author of this thesis

B-4. Educational resource: a meiosis activity task

Selected pages of meiosis activity task with respect to the follow-up meiosis simulation activity-kit (English version)

Students' Worksheet

-MEIOSIS & GENETIC DIVERSITY-

Purpose:

1. To simulate chromosomes behaviour during meiosis
2. To illustrate the way meiosis generate genetic variation

This model uses assumption that chromosomes are condensed at all time (including during S-phas in cell cycle). Chromosome is represented as rod-like structure (look at figure 1). Coloured sticker labels represent centromere and genes. Dot sticker symbolises centromere, while a square sticker represents gene. Genes are in a specific locus (look at Figure 1). Use distinct colours to represent genes from a paternal to a maternal line.
In this model, you will simulate meiosis in a cell of a certain organism. The cell has 10 chromosome

Material:

1. Chromosome model
2. Dot and square stickers
3. A coin

Preparation:

1. You will receive 4 envelopes, i.e. PATERNAL CHROMOSOME, MATERNAL CHROMOSOME, PART and PART B.
2. Put the coloured sticker available in each envelope to chromosome model (look at Figure 1 for further reference)
3. Put model of chromosomes from PATERNAL CHROMOSOME and MATERNAL CHROMOSOME or the table. These are all chromosomes in the parental cell (a reproductive cell).

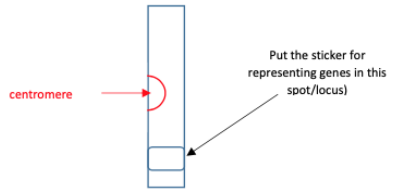


Figure 1. Chromosome model

Procedure:

A. PRIOR TO MEIOSIS

1. Count the number of chromosome in the parental cell (look at preparation no. 3) an Table-1.
2. Prior to meiosis, cell will replicate its DNA. Find the correct duplicate for each chrom them together so that each chromosome consists of sister chromatids.
3. Count the number of chromosome after replication.

B. MEIOSIS

Meiosis occurs in two successive stages, Meiosis 1 and 2. The name for each phase in the is provided in the Observation Sheet (1 and 2).

4. Look at the model of chromosome on your table. Think what will happen to the mod chromosomes in prophase I. Arrange your model of chromosome accordingly. Write note about the chromosome arrangement in this phase.
5. Move your model of chromosomes to simulate the next phase, metaphase I. Write a this event.
6. Continue to simulate chromosome behaviour in other phases to complete meiosis.
7. To demonstrate two notable events in meiosis, **the crossing over and the random di of chromosomes,** follow below instruction:
   (notes: You must remember in what phase that these two events occur)

Crossing over (gene recombination)	***Random distribution of chromosomes***
Crossing over is performed as exchanging (gene) stickers.	*Random distribution is performed as excha position of homologous pair or chromatids.*
a. Focus on one specific locus in the homologous pairs b. Toss a coin. If you get "head", exchange the alleles between non-sister chromatids. Do nothing if you get "tail". c. Do the same thing (a-b) to all loci.	***a. In Meiosis I:*** a. Have your homologous chromoso line. b. First, focus on the first pair on you hand side. c. Toss a coin. If you get "head", excl position of the chromosomes in a nothing if you get "tail". d. Do the same thing (c) for all pairs. ***b. In Meiosis II:*** a. Have your chromosomes in line. b. First, focus on the chromosome o left-hand side. c. Toss a coin. If you get "head", excl position of the chromatids in a chromosome. Do nothing if you ge d. Do the same thing (c) for all chrom

c. AFTER MEIOSIS

Look at the result of the group next to you. At the beginning, you are working with the sar chromosomes (the same parental cell).

8. Find the differences between gametes from your group and those from a group next Write down your answers in the observation sheet.

Table 1. Number of chromosomes in various stages of meiosis

Stages	Number of cell	Number of chromosomes (in each cell)
PRIOR TO MEIOSIS		
Before replication	1 parental cell	
After DNA replication	1 parental cell	
MEIOSIS		
The beginning of Prophase I	1 parental cell	
The end of meiosis I	2 daughter cells	
The beginning of Prophase II	2 daughter cells	
The end of meiosis II	4 daughter cells	
AFTER MEIOSIS		
Gametes	4 cells	

Gametes variation between groups:

B-5. Educational resource: a meiosis activity task

Selected pages of meiosis activity task with respect to the follow-up meiosis simulation activity-kit (Indonesian version)

LEMBAR KERJA

-MEIOSIS & KERAGAMAN GENETIS-

TUJUAN:

1. Menyimulasikan perilaku kromosom selama meiosis
2. Mengilustrasikan bagaimana meiosis berperan dalam menimbulkan keragaman genetis

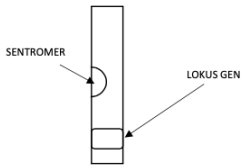
Dalam simulasi meiosis ini, kita mengasumsikan kromosom selalu dalam keadaan berkondensasi (memadat) selama siklus sel dan meiosis. Anda akan menyimulasikan apa yang terjadi pada kromosom sel induk kelamin yang diploid (2n) dari suatu individu yang memiliki 10 kromosom pada saat mereka melakukan pembelahan meiosis.

BAHAN:

1. Kromosom (model)
2. Stiker berwarna berbentuk lingkaran dan persegi
3. Koin

ANALOGI MODEL:

1. Kromosom yang berkondensasi dilambangkan dengan struktur berbentuk batang.
2. Setiap kromosom terdiri dari satu untai DNA untai ganda (*double helix*)
3. Sentromer terletak pada area yang berbentuk setengah lingkaran. Pada keadaan berduplikasi, area sentromer disimbolkan dengan stiker lingkaran.
4. Gen tertentu pada kromosom dikenali dari lokus gen pada kromosom
5. Perbedaan alel gen kromosom paternal dengan alel gen kromosom maternal disimbolkan dengan menggunakan warna stiker label yang berbeda



Gambar 1. Detil model kromosom

CARA KERJA:

A. PERAKITAN MODEL KROMOSOM:

1. Anda akan menerima model kromosom yang terdiri dari 4 bagian: PATERNAL-1, MATERNAL-1, PATERNAL-2 dan MATERNAL-2.
2. Tempelkan stiker warna yang tersedia dalam amplop pada model kromosom.

B. SIMULASI MEIOSIS

1. TAHAPAN PRA MEIOSIS

Sebelum membelah, sel akan menggandakan materi genetiknya (DNA). Penggandaan materi genetik tampak sebagai duplikat kromosom yang masih berlekatan di sentromer. Tiap duplikat disebut kromatid.

a. Gabungkan kromosom dari amplop PATERNAL-1 dan MATERNAL-1. Ini adalah kromosom pada sel kelamin induk.
b. Sel ini bersifat diploid (2n) karena terdiri dari 2 set kromosom. Tentukan bagaimana Anda mengenali kedua set kromosom ini. Tuliskan hasil Anda pada Lembar Pengamatan.
c. Hitung jumlah kromosom sel induk kelamin. Tuliskan pada Tabel-1.
d. Simulasikan replikasi DNA dengan menemukan kopian tiap kromosom. Rekatkan kopian kromosom pada daerah sentromer.
e. Tentukan mana yang dimaksud sebagai kromatid bersaudara dan kromosom homolog. Tuliskan pengertian Anda pada Lembar pengamatan.
f. Hitung kembali jumlah kromosom (setelah proses penggandaan) dan tentukan ploidy sel pada tahapan ini. Catat hasilnya pada Tabel-1.

2. TAHAPAN PEMBELAHAN MEIOSIS

Sel induk kelamin mengalami meiosis yang terjadi melalui dua tahapan berurutan, Meiosis I dan Meiosis II. Urutkan ap yang terjadi pada kromosom dalam setiap tahapan pembelahan sel.

g. Visualisasikan gerakan kromosom homolog/ kromosom/ kromatid selama tahapan pembelahan meiosis I dan II. Kaitkan gerakan kromosom ini dengan komponen lain yang terlibat dalam pembelahan berikut ini:
   1. membran nukleus
   2. membran sel
   3. sentromer
   4. benang spindel
h. Gunakan instruksi di bawah untuk menyimulasikan peristiwa **pindah silang dan distribusi random kromosom:**

Pindah silang (rekombinasi gen)	***Distribusi random kromosom***
Pindah silang ditampilkan sebagai pertukaran stiker label berwarna. a. Pilih satu lokus gen pada salah satu kromosom homolog. b. Lemparkan koin. Jika mendapatkan "kepala", tukar alel paternal dengan alel maternal. Jika mendapatkan "ekor", jangan mempertukarkan alel. c. Ulangi langkah a-b untuk semua lokus gen yang ada pada model kromosom.	*Distribusi random berpengaruh pada arah pengelompokan kromosom.* ***Meiosis I*** a. Pilih salah satu pasangan kromosom homolog. b. Lemparkan koin. Jika mendapatkan "kepala", tukar posisi kromosom pada pasangan homolog. Jika mendapatkan "ekor", biarkan kromosom dalam posisi awal. c. Ulangi langkah a-b pada semua pasangan kromosom homolog ***Meiosis II*** a. Pilih salah satu kromosom b. Lemparkan koin. Jika mendapatkan "kepala", tukar posisi kromatid pada kromosom. Jika mendapatkan "ekor", biarkan posisi kromatid seperti awal. c. Ulangi langkah a-b pada semua kromosom yang ada dalam sel.

Catatan: tetapkan terlebih dahulu mana yang menjadi sisi "ekor" dan "kepala" pada koin sebelum melakukan pelemparan.

i. Tuliskan gerakan kromosom di tiap tahapan meiosis pada Lembar Meiosis 1 Lembar Meiosis 2
j. Catat keadaan kromosom pada akhir setiap tahapan meiosis I dan II. Hitung jumlah kromosom dan tetapkan ploidy sel anakan dan tuilskan pada Tabel-1 Lembar Pengamatan.

Lembar Pengamatan

Tabel 1. Perbandingan jumlah kromosom sel pada berbegai tahapan meiosis

Keadaan sel	Jumlah sel	Jenis ploidi sel	Jumlah kromosom (per satu sel)
SEBELUM MEIOSIS			
Keadaan sel awal	1 sel induk	Diploid (2n)	
Setelah replikasi DNA	1 sel induk		
MEIOSIS			
Awal prophase I	1 sel induk		
Akhir telophase I	2 sel anakan		
Awal prophase II	2 sel anakan		
Akhir telophase II	4 sel anakan		
SETELAH MEIOSIS			
Sel gamet	4 sel anakan		

Perbedaan 2 set kromosom pada sel induk kelamin:

Kromatid bersaudara:

Kromosom homolog:

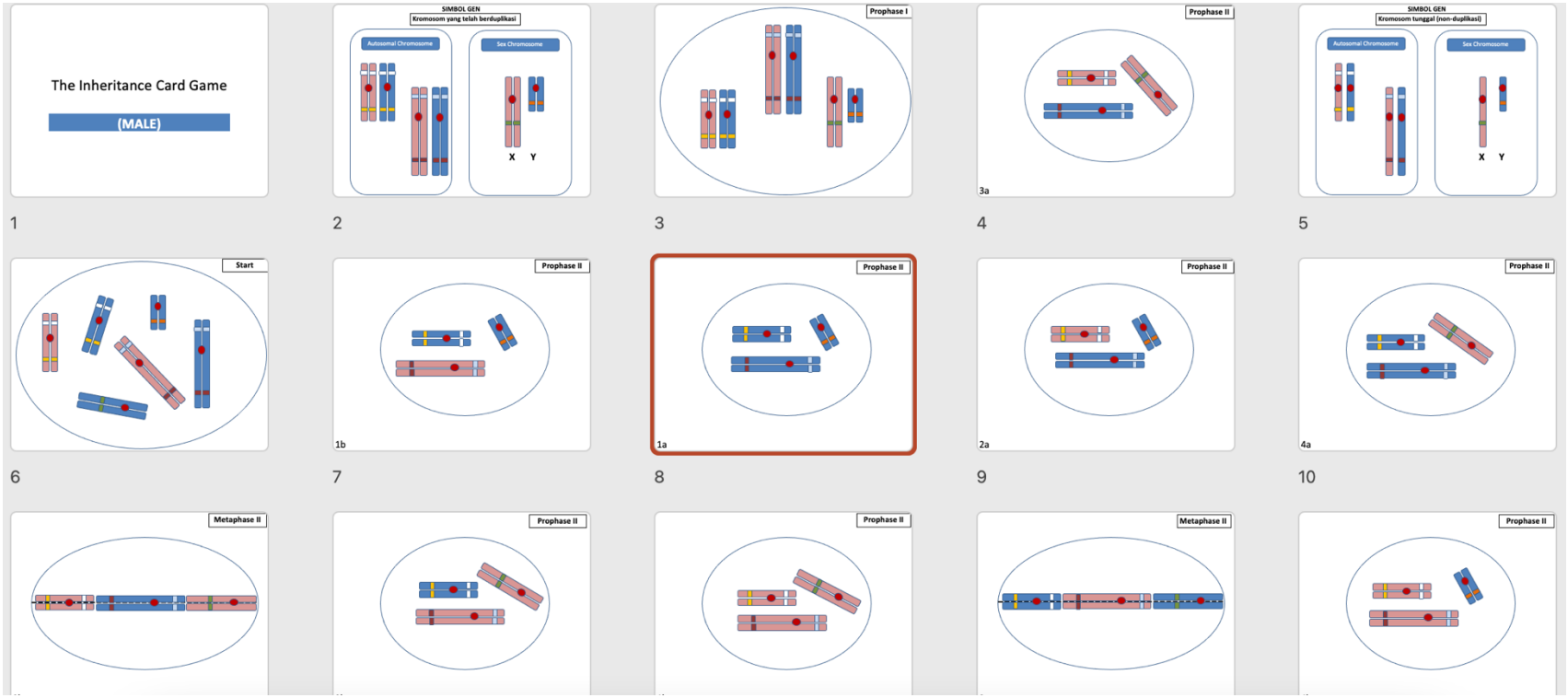
Hasil pengamatan perbedaan sel GAMET antara GRUP ANDA dengan GRUP SEBELAH ANDA:

Appendices-C

This section presents all appendices related to Chapter 5 in the main body of thesis.

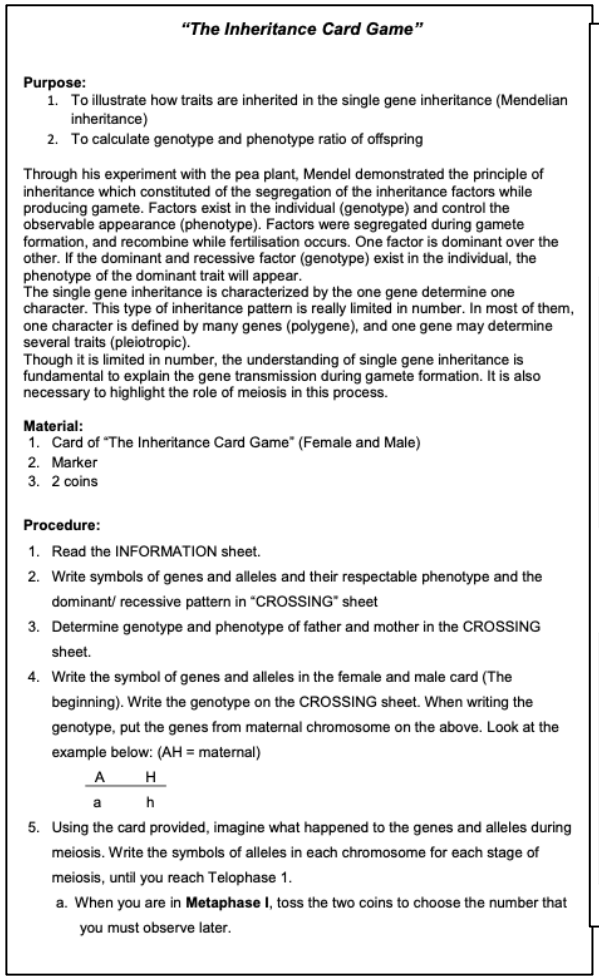
C-1. Educational resource: the inheritance cards (example: male cards)

A sequence of male cards showing autosomes and sex chromosomes (X and Y) with space for writing alleles on them. These cards show how meiosis happen and how probabilities in random fertilization occur



C-2. Educational resource: an inheritance activity task

Selected pages of worksheet of inheritance cards activity (English version)



"The Inheritance Card Game"

Purpose:

1. To illustrate how traits are inherited in the single gene inheritance (Mendelian inheritance)
2. To calculate genotype and phenotype ratio of offspring

Through his experiment with the pea plant, Mendel demonstrated the principle of inheritance which constituted of the segregation of the inheritance factors while producing gamete. Factors exist in the individual (genotype) and control the observable appearance (phenotype). Factors were segregated during gamete formation, and recombine while fertilisation occurs. One factor is dominant over the other. If the dominant and recessive factor (genotype) exist in the individual, the phenotype of the dominant trait will appear.
The single gene inheritance is characterized by the one gene determine one character. This type of inheritance pattern is really limited in number. In most of them, one character is defined by many genes (polygene), and one gene may determine several traits (pleiotropic).
Though it is limited in number, the understanding of single gene inheritance is fundamental to explain the gene transmission during gamete formation. It is also necessary to highlight the role of meiosis in this process.

Material:

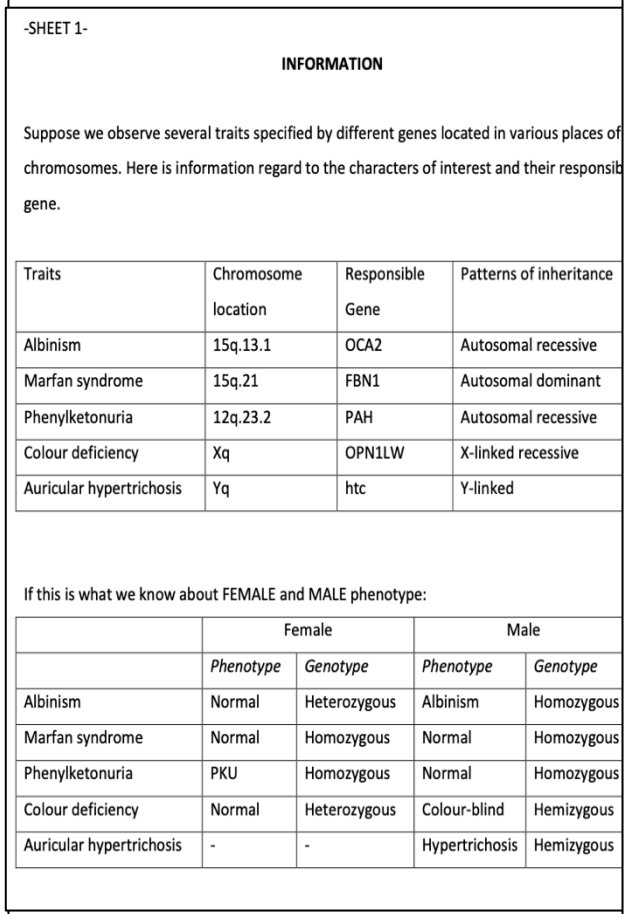
1. Card of "The Inheritance Card Game" (Female and Male)
2. Marker
3. 2 coins

Procedure:

1. Read the INFORMATION sheet.
2. Write symbols of genes and alleles and their respectable phenotype and the dominant/ recessive pattern in "CROSSING" sheet
3. Determine genotype and phenotype of father and mother in the CROSSING sheet.
4. Write the symbol of genes and alleles in the female and male card (The beginning). Write the genotype on the CROSSING sheet. When writing the genotype, put the genes from maternal chromosome on the above. Look at the example below: (AH = maternal)

   $\frac{A \quad H}{a \quad h}$

5. Using the card provided, imagine what happened to the genes and alleles during meiosis. Write the symbols of alleles in each chromosome for each stage of meiosis, until you reach Telophase 1.
   a. When you are in **Metaphase I**, toss the two coins to choose the number that you must observe later.



-SHEET 1-

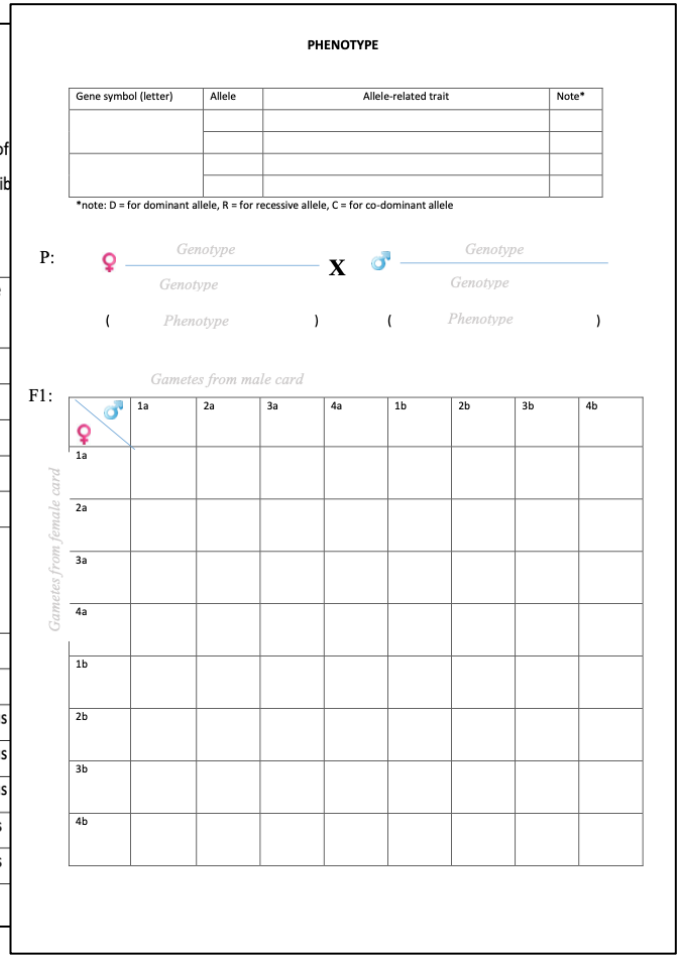
INFORMATION

Suppose we observe several traits specified by different genes located in various places of chromosomes. Here is information regard to the characters of interest and their responsib gene.

Traits	Chromosome location	Responsible Gene	Patterns of inheritance
Albinism	15q.13.1	OCA2	Autosomal recessive
Marfan syndrome	15q.21	FBN1	Autosomal dominant
Phenylketonuria	12q.23.2	PAH	Autosomal recessive
Colour deficiency	Xq	OPN1LW	X-linked recessive
Auricular hypertrichosis	Yq	htc	Y-linked

If this is what we know about FEMALE and MALE phenotype:

	Female		Male	
	Phenotype	*Genotype*	*Phenotype*	*Genotype*
Albinism	Normal	Heterozygous	Albinism	Homozygous
Marfan syndrome	Normal	Homozygous	Normal	Homozygous
Phenylketonuria	PKU	Homozygous	Normal	Homozygous
Colour deficiency	Normal	Heterozygous	Colour-blind	Hemizygous
Auricular hypertrichosis	-	-	Hypertrichosis	Hemizygous



PHENOTYPE

Gene symbol (letter)	Allele	Allele-related trait	Note*

*note: D = for dominant allele, R = for recessive allele, C = for co-dominant allele

P: ♀ Genotype / Genotype (Phenotype) **X** ♂ Genotype / Genotype (Phenotype)

F1: Gametes from male card

♀ \ ♂	1a	2a	3a	4a	1b	2b	3b	4b
1a								
2a								
3a								
4a								
1b								
2b								
3b								
4b								

Gametes from female card

C-3. Raw data of pre and post GCA test (UK and IND-2)

The correct answers for the GCA questions used in this study were provided by Smith, Wood and Knight (2008) and were used under an embargo agreement with the authors of the paper. Therefore, the raw data of the pre and post-test UK and IND-2 are not published here, as they are part of the embargo agreement, but are available on request to the author of this thesis

Appendices-D

This section presents all appendices related to Chapter 6 of the main body of thesis.

D-1. Educational resource: The gene concept booklet (Version 1 in English)

Selected pages of the gene concept booklet ver.1 written in English

THE BRIEF DEFINITION OF

GENE

GENE in Biochemical-Classical era
(1941-1950s (prior to the discover of DNA structure)

In biochemical-classical model, gene is defined as a locus in chromosome which physically composed of DNA molecule and specify the production of protein/enzyme in metabolic the pathways that determine the observed trait. It could be transmitted, recombined and mutated.

Muller (1927) did a study which led to the understanding that gene has a physical, molecular basis. This initial finding initiated the extensive research to the chemical property of gene.

Oswald Avery, Colin MacLeod and Maclin McCarty (1944) discovered that the chemical structure of gene is deoxyribonucleic acid (DNA). Their study was based on previous study of **Griffith (1928)** which investigate the mechanism of transformation in bacteria using *Pneumococcus*. He found that gene could be transformed from deadly variety of dead bacteria to the harmless lived bacteria, changing the harmless strain into the dreadful one, they used this principle in conducting their study of the same bacteria in-vitro. Avery et al. found that DNA is the component in the transformed molecule, which implied that DNA is the constituent of gene. **Alfred Hershey and Martha Chase** (1952) confirmed this finding through their experiment with bacteriophage. They labelled protein capsule with radioactive sulphur-35 and DNA inside capsule with radioactive phosphorous-32 (Finkel, 2012; Smith and Adkinson, 2008)

Thus, so far gene was seen as unit of inheritance which made of DNA, located on chromosome, could be mutated, recombined and transmitted to offspring, and work to specify protein involved in the metabolic pathways of particular observed trait.

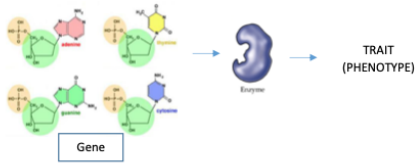


Figure 3. Different from previous assumption that gene may act as enzyme, the finding of gene made up of nucleotide (DNA) confirmed that gene specified enzyme in a metabolic pathways that define the trait

GENE in Post ENCODE era
(2007-present)

In ENCODE era, a gene is defined as a union genomic entity which code for functional product, either RNA or protein

ENCODE (Encyclopedia of DNA elements) is an international consortium of geneticists that focuses on seeking the meaning of sequence of DNA and determine the function of the various identified elements. The striking finding of ENCODE is the confirmation that the vast amount of DNA, not annotated to gene (i.e. DNA coding protein), is transcribed into RNA. The investigation to **Transcriptionally Active region (TARSs)** showed that majority of DNA transcribed into non- protein coding-RNA (ncRNA). Although the specific function of this ncRNA is not known yet, but since human had more or less protein-coding gene (about 21,000 number of genes) as that of roundworms, it is assumed that ncRNA might have the regulatory effect which specify human to roundworm. Also, the elements of ncRNA has been conserved over evolution (find in many species for the same locus) which lead to the think that these segments play an important role. Therefore, through this finding, it seems that the central dogma becomes no longer applicable in defining gene.

Furthermore, gene sequences can be transcribed into more than one primary RNA transcript (hnRNA) by using different **transcription start sites (TSSs)** within the one gene-one polypeptide paradigm. This finding contradicted the one gene-one polypeptide paradigm. The fact that primary hnRNA transcript can be alternatively spliced to generate distinct mRNA (mature mRNA) which produce different polypeptide also raise a question of whether the referred DNA sequence should be counted as one gene or more.

Based on their findings, ENCODE scientists have called for the revision of gene definition. The new definition incorporate the production of functional product either as protein or RNA for defining a gene. Gerstein et al. (2007) proposed gene as "a union of genomic sequences encoding a coherent set of potentially overlapping functional products" (p.677). By so doing, he explicated that gene could be either DNA or RNA (a genomic sequence) which code for either RNA or protein, and the overlapping genomic region which produce different products will still be counted as one gene. Similar to previous definition, King et al (2013) also define a gene as "a genomic sequences that are required, in sequential or overlapping combinations, to produce one or more functional RNA or protein products, that contribute to a particular phenotype"(p.182).

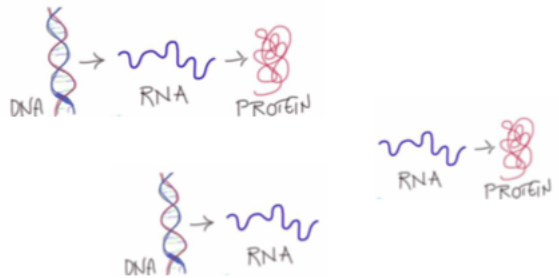
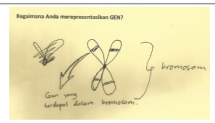
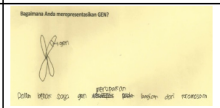
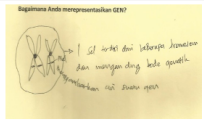
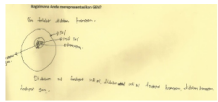
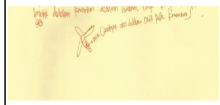


Figure 7. Gene is defined by its functionality in the genome. It could be a coding DNA, non-coding DNA, or RNA but which produce a function.

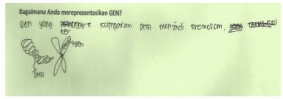
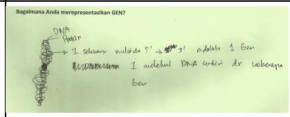
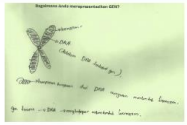
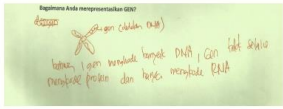
D-2. Example of data analysis on the pre and post concept test of a gene (cohort sample: IND-2)

Selected pages of data coding analysis extracted from participants' answer sheets of concept test of a gene.

PRE TEST:

Cohort	PseudoName	PRE TEST						
		VERBAL definition of gene		PICTORIAL definition of gene		VERBAL DEFINITION ANALYSIS		
		Original language	English translation	Picture	Description	Structure	Location	Function
Group 1	Azmi	Gen adalah **seperangkat unit** yang terdapat di dalam kromosom dan **memiliki sifat** suatu individu dan akan diturunkan pada anakannya.	*Gene is* ***a unit*** *located* ***inside the chromosome,*** *it* ***contains individual trait*** *, and it* ***will be transmitted*** *to its offspring.*		(1) Gene is a segment (band) on a chromosome; (2) ***"gene is located inside (on) the chromosome"***	a trait bearing unit	inside the chromosome	transmission (passive)
	Mimi	Gen merupakan **bagian kecil dari kromosom** yang **dapat menurunkan sifat** pada anakan dari induknya	*Gene is* ***a*** ***small part of a chromosome*** *which is able to* ***transmit*** *the trait from parents to the offspring*		***(1) "gene is part of chromosome"***	a small part of chromosome	-	transmission (active)
	Roni	Gen ada **kode genetik** dari indukan yang diturunkan melalui keturunan yang membawa sifat-sifat dari suatu individu	*Gene is* ***a genetic code*** *which is* ***transmitted from parents to offspring*** *; the codes bear the characteristics of an individual*		(1) Gene (allele) is a band on the chromosome. (2)***"a cell consists of several chromosomes, and it contains genetic code"; (3)"Allele represents a characteristic of a gene"***	a trait bearing genetic code	-	transmission (passive)
	Vani	**Gen merupakan sifat pembawa** pada makhluk hidup, yang mana memberikan sifat tertentu pada tiap makhluk hidup, yang diturunkan dari induk ke anaknya	*Gene is* ***a carrier*** *of the living-beings, which* ***specifies a trait, and is transmitted*** *from parents to offspring*		(1) gene is located inside (at any points of) a **chromosome** inside a nucleus within a cell	a trait determining carrier		to specify a trait; transmission (passive)
Group 2	Aliya (IS)	Gen adalah unit pewarisan sifat pada suatu organisme, gen terletak di dalam kromosom. Di dalam DNA terdapat gen. Gen ibarat suatu penyandi sifat pada makhluk hidup yang memberikan variasi genetic	*Gene is* ***a unit of heredity of an organism*** *; the gene is located* ***inside the chromosome, in the DNA.*** ***Additional notes:*** *Gene looks like a* ***trait encoder*** *of an organism which produces* ***genetic variation.***		(1) Gene is located **inside the DNA** inside the **chromosome**	unit of inheritance; a trait decoder	*inside the chromosome, inside the DNA*	to specify a trait/to give rise to the genetic variation
								

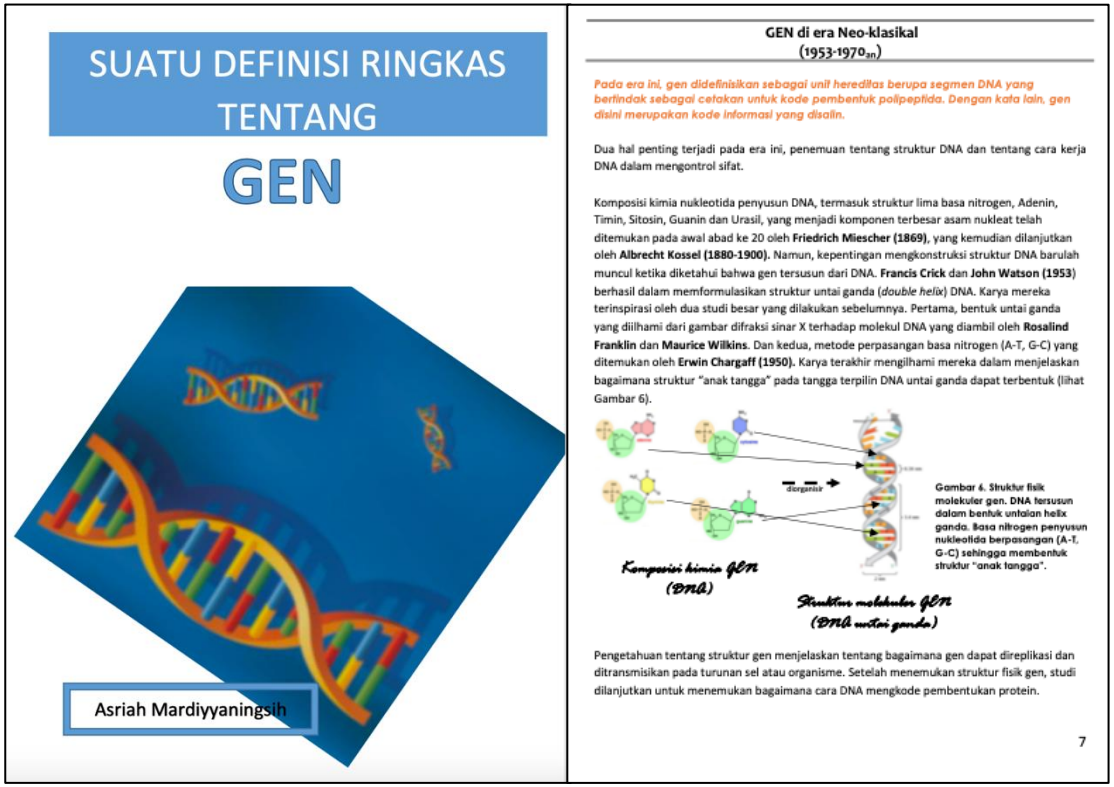
POST TEST:

Cohort	PseudoName	POST TEST						
		VERBAL definition of gene		PICTORIAL definition of gene		VERBAL DEFINITION ANALYSIS		
		Original language	English translation	Picture	Description	Structure	Location	Function
Group 1	Azmi	Gen adalah suatu unit senyawa yang terdapat pada kromosom yang mana mengandung kodean sifat dari suatu individu dan dapat diturunkan kepada individu berikutnya (anakannya)	*Gene is **a compound unit** located **on the chromosome**, it **contains code of a trait** of an individual, and **it can be transmitted** to the next generation (offspring)*		(1) gene is part of (a substance) that makes up a chromosome (presumed as DNA); (2) a chromosome consists of contiguous strand of DNA (including centromere)	a trait-related-code bearing compound unit	on the chromosome	transmission (passive)
	Mimi	Gen merupakan gabungan dari beberapa DNA yang membentuk satu kromosom. Bentuk kromosom seperti kumparan benang yang padat. Terdapat beberapa gen di dalam kromosom. 1 gen merupakan 1 DNA yang dimulai dari 5' sampai 3'	*Gene is a **combination of several DNAs** which **constitute a chromosome**. The chromosome looks like a condensed coiling thread. There are **several genes in(side) the chromosome**. **One gene is one DNA** stretching from 5' to 3'.*		(1) one gene is a loop (of DNA) locating on an arm of chromosome (2) gene is coiled to form DNA which is later become chromosome	a molecule of DNA on a chromosome		x
	Roni	Gen itu adalah suatu representasi dari DNA (berasal dari DNA yang terdapat di kromosom. Gen berfungsi menurunkan sifat dari suatu individu ke keturunannya. 1 gen berarti sama dengan 1 sekuens DNA yang mengandung kode-kode genetik.	*Gene is a **representation of DNA/is made up of DNA locating** **on the chromosome**. Gene **serves to transmit a trait** from an individual to its descendant. One gene equals to **one DNA sequence which contains the genetic codes.***		(1) a gene is a sequence of 5'-3'; a molecule of DNA consists of several genes (2) A chromosome is made up of DNA and protein (contiguous strand, including centromere)	a genetic code bearing sequence of DNA	on chromosome	transmission (active)
	Vani	Gen merupakan sifat yang diwariskan oleh orang tua ke anakannya. Letak gen di kromosom, tepatnya di DNA, dimana DNA ini di kromosom adalah merupakan susunan-susunan yang membentuk kromosom sehingga membawa sifat yang dapat diturunkan (gen).	*Gene is **a trait** that **is transmitted from parents to their offspring**. Gene is **located on the chromosome, particularly on the DNA.** DNA makes up a chromosome, so it carries **the transmittable trait***		(1) "twisted structures of DNA make up a chromosome" (including centromere region) (2) "gene is located inside the DNA"	a trait	on the DNA on the chromosome	transmission (passive)
Group 2	Aliya (IS)	Gen adalah sekuen DNA yang panjang yang terdiri dari basa nitrogen yang diawali dengan daerah promotor, UTR, exon, intron dan exon. Gen terletak di dalam kromosom.	*Gene is **a long sequence of DNA**, consists of nitrogen base which is started by **promoter region, UTR, exon, intron and exon**. Gene is located **inside the chromosome**.*		**(1)** Gene is located inside the DNA on the chromosome **(2)** "*one gene encodes many DNAs. A gene does not always encode protein, but (could) encode only RNA*".	a transcriptional unit of DNA	inside the chromosome	to encode many DNAs/protein/RNA
					The three concepts of gene: (1) as a			

PseudoName	PICTORIAL DEFINITION ANALYSIS		MISCONCEPTIONS		Historical Model of gene				
	Structure/location/function	Function of gene	Verbal	Pictorial	V	P	Model	NOTES	NOTES
Azmi	a dimensionless point of (DNA that makes up an entire) chromosome	-			*Classical*	*Neoclassical*	*Hybrid (C/N)*	*although he mentioned code of a trait (DNA as an information code), but he did not refer that to DNA*	
Mimi	one molecule of DNA inside a chromosome	-	(1) she considered that one gene is one molecule of DNA (other genes have different molecule of DNA); (2) she still adopt the term "inside" a chromosome	1 gene, 1 molecule of DNA	*Neoclassical*	*Neoclassical*		*because she mention 5'-->3' which is known only after the discovery of DNA double helix*	
Roni	a sequence 5'-3' of DNA that makes up an entire chromosome	-	Two views of gene: Gene is made up of DNA, and gene as a segment of DNA; "1 molecule of DNA consists of **several** genes"		*Neoclassical/ Clasical*	*Neoclassical*		*The DNA based idea, but still incorporated the trait transmission*	improvement in the DNA and protein as the structure of chromosome
Vani	a dimensionless point of DNA that makes up a chromosome	-	"*DNA makes up a chromosome, so it carries the transmittable trait"* showed that DNA carries the trait	"*inside the DNA there are genes*" gene is located inside the DNA, rather than as a segment of DNA	*Classical/ Biochemical*	*Neoclassical*		*DNA had been mentioned but not explain the structure or function (biochemical), and the focus of transmission and consider gene as trait located on chromosome*	gene-->DNA-->chromosome (gene as the smallest unit)
Aliya (IS)	a dimensionless point of DNA that makes up a chromosome	-	*(1) "gene is located "inside" the chromosome"*	(1) gene is contained **inside the DNA** (no clear visualisation of its form); (2) "*one gene encodes many DNA…"* is not understandable	*Modern/ Classical*	*Neoclassical*		*a molecular approach of gene (modern) but still followed by the classical idea of gene lcating on the chromosome*	gene is located inside the DNA on the chromosome, no further explanation of the function/structure of DNA (neoclassical)

D-3. Educational resource: The gene concept booklet (Version 2 in Indonesian)

Selected pages of the gene concept booklet ver.2 written in Indonesian.



SUATU DEFINISI RINGKAS TENTANG

GEN

Asriah Mardiyyaningsih

GEN di era Neo-klasikal
(1953-1970$_{an}$)

Pada era ini, gen didefinisikan sebagai unit hereditas berupa segmen DNA yang bertindak sebagai cetakan untuk kode pembentuk polipeptida. Dengan kata lain, gen disini merupakan kode informasi yang disalin.

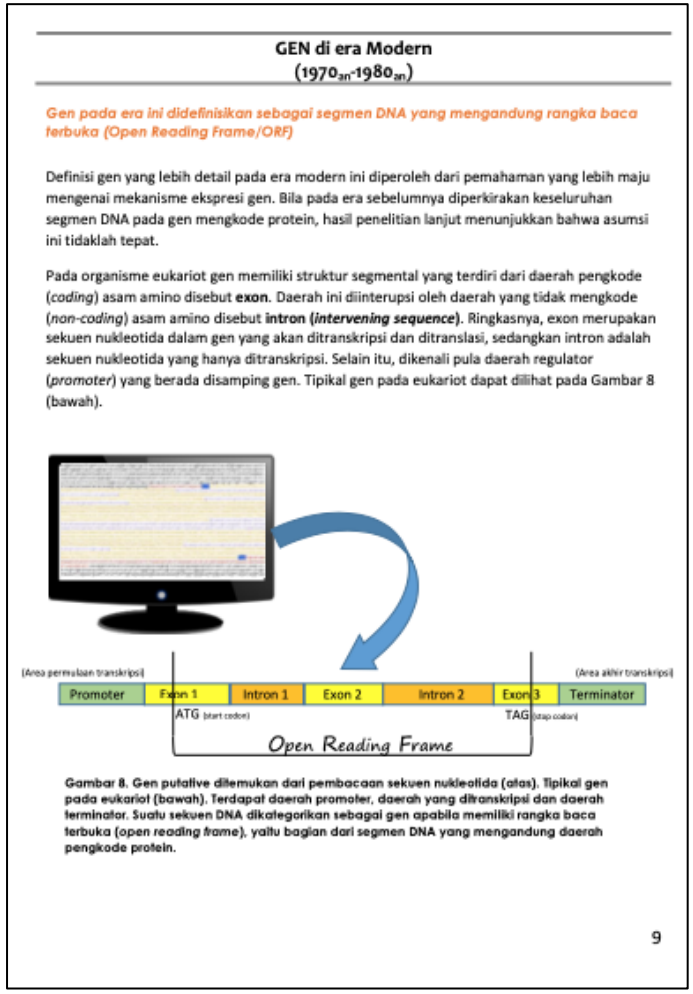
Dua hal penting terjadi pada era ini, penemuan tentang struktur DNA dan tentang cara kerja DNA dalam mengontrol sifat.

Komposisi kimia nukleotida penyusun DNA, termasuk struktur lima basa nitrogen, Adenin, Timin, Sitosin, Guanin dan Urasil, yang menjadi komponen terbesar asam nukleat telah ditemukan pada awal abad ke 20 oleh **Friedrich Miescher (1869)**, yang kemudian dilanjutkan oleh **Albrecht Kossel (1880-1900).** Namun, kepentingan mengkonstruksi struktur DNA barulah muncul ketika diketahui bahwa gen tersusun dari DNA. **Francis Crick** dan **John Watson (1953)** berhasil dalam memformulasikan struktur untai ganda (*double helix*) DNA. Karya mereka terinspirasi oleh dua studi besar yang dilakukan sebelumnya. Pertama, bentuk untai ganda yang diilhami dari gambar difraksi sinar X terhadap molekul DNA yang diambil oleh **Rosalind Franklin** dan **Maurice Wilkins**. Dan kedua, metode perpasangan basa nitrogen (A-T, G-C) yang ditemukan oleh **Erwin Chargaff (1950).** Karya terakhir mengilhami mereka dalam menjelaskan bagaimana struktur "anak tangga" pada tangga terpilin DNA untai ganda dapat terbentuk (lihat Gambar 6).

Gambar 6. Struktur fisik molekuler gen. DNA tersusun dalam bentuk untaian helix ganda. Basa nitrogen penyusun nukleotida berpasangan (A-T, G-C) sehingga membentuk struktur "anak tangga".

Pengetahuan tentang struktur gen menjelaskan tentang bagaimana gen dapat direplikasi dan ditransmisikan pada turunan sel atau organisme. Setelah menemukan struktur fisik gen, studi dilanjutkan untuk menemukan bagaimana cara DNA mengkode pembentukan protein.

7



GEN di era Modern
(1970$_{an}$-1980$_{an}$)

Gen pada era ini didefinisikan sebagai segmen DNA yang mengandung rangka baca terbuka (Open Reading Frame/ORF)

Definisi gen yang lebih detail pada era modern ini diperoleh dari pemahaman yang lebih maju mengenai mekanisme ekspresi gen. Bila pada era sebelumnya diperkirakan keseluruhan segmen DNA pada gen mengkode protein, hasil penelitian lanjut menunjukkan bahwa asumsi ini tidaklah tepat.

Pada organisme eukariot gen memiliki struktur segmental yang terdiri dari daerah pengkode (*coding*) asam amino disebut **exon**. Daerah ini diinterupsi oleh daerah yang tidak mengkode (*non-coding*) asam amino disebut **intron (*intervening sequence*)**. Ringkasnya, exon merupakan sekuen nukleotida dalam gen yang akan ditranskripsi dan ditranslasi, sedangkan intron adalah sekuen nukleotida yang hanya ditranskripsi. Selain itu, dikenali pula daerah regulator (*promoter*) yang berada disamping gen. Tipikal gen pada eukariot dapat dilihat pada Gambar 8 (bawah).

Gambar 8. Gen putative ditemukan dari pembacaan sekuen nukleotida (atas). Tipikal gen pada eukariot (bawah). Terdapat daerah promoter, daerah yang ditranskripsi dan daerah terminator. Suatu sekuen DNA dikategorikan sebagai gen apabila memiliki rangka baca terbuka (*open reading frame*), yaitu bagian dari segmen DNA yang mengandung daerah pengkode protein.

9

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