Spicing up your space education with cansats, rockets and hackathons – the SUN Recipe Book

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***Abstract*—The UK-based "Space Universities Network" (SUN) was formed in 2016 with the aim of enhancing the quality of learning and teaching by providing support and resources to the space science and engineering higher education community. It now has 60 members from 30 different Universities around the UK. SUN's objectives are to facilitate the creation of a skilled workforce of graduates who can meet the challenges of future scientific and commercial exploitation of space. The network addresses this need by helping to inspire students to join the space sector and ensuring they are well equipped at University to contribute. SUN enables the developing, sharing and promotion of effective practice and innovation in the delivery of university-level space science and engineering curricula. One of the ways that effective practice and innovation is disseminated is by the collection of case studies. In this paper, a collection of case studies from different members of the network is described.**

The case studies cover a wide variety of student activities run by staff and/or students including Satellite in a SodaCan (CanSat) competitions, water rocket and rocket building, Earth observation data hackathons, astrodynamics workshops using GMAT software, Lunar rover model building, cubesat projects, remote microscope investigation of samples, satellite applications data workshops and ESA 'drop your thesis' projects. For each case study, those running the activity completed a standard format template of 1-3 pages which describes: What was the purpose? How was it integrated into the curriculum (if at all)? How did it work? What materials do you need and how much did it cost in time and money? What problems were encountered? What feedback did you have? The paper describes each case study briefly. These are now publicly available on the SUN website (spaceuniversitiesnetwork.ac.uk) and are accessible to all. More cases studies are welcome and are being submitted. It is hoped that these will inspire other Universities who wish to spice up their space courses with some interesting recipes!

Keywords*—*higher education; case studies; resources;

I. Introduction

The world space economy is expected to grow to $400 billion by 2030 and the UK has ambitious plans to secure 10% of the global market, growing the space workforce by a further 100000 jobs. Training new space engineers and scientists is therefore critical. It is recognized that there is a shortfall in Science, Technology Engineering, and Maths (STEM) graduates. A UK accreditation body called the 'Institute of Engineering and Technology' has produced a report on skills, based on surveys of employers. These surveys established that 62% of UK engineering employers are concerned about graduate skills, and of those, 59% say that is because Engineering and technology degrees do not develop sufficient practical skills. 68% of employers are concerned that the education system will struggle to keep up with the skills required for technological change [1]. Against this backdrop, the UK-based "Space Universities Network" (SUN) was formed in 2016, with the aim of enhancing the quality of learning and teaching in Space Science and Engineering. SUN members wish to enable the development, sharing and

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promotion of effective practice and innovation in the delivery of university-level space science and engineering curricula. In previous work, the aims and objectives, evolution of the network, methods, evaluation of the network has been described [2]. In this work the network have collected together a series of case studies from different UK universities which describe examples of good practice in the field of space teaching and learning.

II. Background

The value of the Space Universities Network comes from the collective intention to advance learning in Space Higher Education, with a particular focus on space science & engineering. The objectives of the case studies were to share good practice by giving university staff and students the opportunity to briefly describe their experiences of certain innovative curricular and extra-curricular projects and exercises in a short format. Many of the projects are active learning-based projects involving the acquisition of practical skills as well as design and research skills.

For each case study, those running the activity completed a standard format template of 1-3 pages which describes: what was the purpose? How was it integrated into the curriculum (if at all)? How did it work? What materials do you need and how much did it cost in time and money? What problems were encountered? What feedback did you have? These questions were designed to elicit information which would be helpful to staff and students in other institutions who were thinking about setting up new activities. The aim was to have a suite of exciting projects which are easy to access (they are all publicly available on the SUN website). The projects cover both curricular and extra-curricular projects, as the same activity can be used in both ways in different Universities. For more details on each project, readers should go to the SUN website.

III. Astrodynamics with GMAT – University of Leicester

The University of Leicester have run an Astrodynamics Mission Simulation 10-credit module over 8 weeks (2 full afternoon computer lab sessions per week) using NASA's General Mission Analysis Tool (GMAT) [3]. The module is taught using a constructivist approach, in which students are found to be more likely to recall and understand concepts which they have discovered independently, than those taught directly. The 30-35 students are set problem questions over the 8-week period and are supported through these in the computer lab sessions by the lecturer and post-graduates. The module is concluded with a mission scenario given to teams of 4 or 5 where students build on the knowledge acquired in the taught elements and apply them to the design of a mission. E.g. plan a mission to Mars using the Phobos-rendezvous using minimum delta V.

Astrodynamics is the study of spacecraft motion, subject to both natural and artificially induced forces. It combines celestial mechanics, attitude dynamics and aspects of positional astronomy to describe spacecraft motion and enable the planning and analysis of missions. The Astrodynamics Mission Simulation module is associated with a third-year undergraduate module comprising 12 lectures and screencasts providing an introduction to Astrodynamics. This Astrodynamics lecture module is not a prerequisite to the Mission Simulation module, however both are very complementary.

This was a staff-led curricular module. The module was run over an 8-week period with 2 full afternoon computer lab sessions per week. The module consists of 6 stages:

1. Walk-through tutorial sessions
2. Introducing Simple Celestial Mechanics
3. Increasing Detail: Perturbations
4. Manoeuvres & Targeting
5. Advancing Beyond Earth
6. Workshop Assessment & Final Challenge

IV. Lunar Rover – University of Surrey

The University of Surrey 'Electronics and Amateur Radio Society' (EARS) sent a team to compete in the UKSEDS Lunar Rover competition to design and build a rover to achieve an objective set by the organisers. This was an extra-curricular project run by students who developed the rover over an academic year and who competed in a final test day.

For the past few years, UKSEDS (UK Students for the Exploration and Development of Space) in tandem with various industrial sponsors has run an annual Lunar Rover competition open to university students in the UK. The goal is to design and build a working lunar rover able to complete a set mission. The lunar rover must be designed to fulfil requirements. For 2016 the mission was: to navigate into the bottom of a lunar crater, retrieve a soil sample, and return to the edge of the crater area. The rover must then return itself with the soil sample to the starting point. The competition entry was student-led and the team comprised: 2 Space Engineering MSc students, 2 second year Electronic Engineering students and 2 first year Electronic Engineering students.

The team's activities were organised in accordance to the schedule set by UKSEDS to complete a PDR and CDR and finally, the test day. The steps taken were as follows:

1. Assemble team for competition entry
2. Apply to enter competition
3. Start designing systems
4. Test designs for wheels/sample collection systems
5. Complete Preliminary Design Review (PDR)
6. Integrate chosen designs together
7. Complete Critical Design Review
8. Complete electronics
9. Compete in final test day

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V. AIAA CANSAT COMPETITION – UNIVERSITY OF MANCHESTER

The Manchester CanSat Project was developed by a team of mainly 2nd and 3rd year undergraduate engineers. They took part in the 2017/18 AIAA & AAS CanSat competition (http://cansatcompetition.com/) held in Texas, USA, which they won. The team designed and built their CanSat to achieve the set mission of the competition over a year with help through funding from sponsors to pay for subsystem components and travel costs. They developed review documents describing progress through the year and performed multiple drops from a rocket to test the systems in the UK, and then travelled to the US for their test flight and presented the outcomes at a post-flight review.

The American Astronautical Society (AAS) runs the CanSat competition annually with the aim to give students an opportunity to design, build, test, launch and operate an engineering product, as opposed to designing a space-related product without any building or testing. The competition specifically is based on designing and building a satellite that fits within a cylindrical envelope of 310 mm length and 125 mm diameter (like a soda can). This project was organised as an extra-curricular activity within the ManSEDS society.

The project started with research and design, progressing to a Preliminary Design review and then followed by a Critical Design review, which required details of manufacture and test and evidence that it would meet the requirements. Good performance in the PDR allowed continuation into the CDR where the top 5 teams competed. This was followed by the test flight where the CanSats were launched and released by rockets at a launch site in Texas provided by the AIAA. Finally, a Post Flight Review was completed involving a presentation and questions.

VI. SPACE MISSIONS IN DEVELOPMENT – UNIVERSITY COLLEGE LONDON

University College London run a curricular 2-week research project into space missions that are currently in development/operation for their MSc Space Science and Engineering students. The students work in pairs and are required to submit a 2500-word report within 2 weeks of the task being set. The research activity is intended to fuel the interest of the students in space by giving them the opportunity to conduct in-depth research into a specific mission that is in development or in operation. The activity aims to improve teamworking skills, report writing skills and general research skills. This is a staff-led curricular activity.

The report must discuss the most innovative, ground-breaking aspects of the mission, the expected scientific discoveries and advance of knowledge it will bring, the technical challenges to be faced and how they will be resolved, mission relevancy and timeliness. Students conduct the research in their own time – they must first select their mission and check with their peers that nobody else is looking at the same mission. Once the mission is selected, they conduct further research into both the scientific objectives of the mission, the technological challenges it faces and how these have been overcome. Conducting this activity so early in the year allows for report writing standards to be established early to improve the quality of submissions later in the year.

VII. GEOSS/HACK SPACE HACKATHON – ESA

The European Space Agency (ESA) ran a Space Hackathon in partnership with the Group on Earth Observations. 30 participants split into 6 teams had 30 hours to create an open-source solution to 1 of 6 challenges focused around meeting the Sustainable Development Goals using Earth Observation data from the Global Earth Observation System of Systems (GEOSS) portal (https://www.geoportal.org/). The primary objective of the GEOSS/HACK hackathon was to challenge participants to develop innovative tools to use satellite data to benefit society, engage more people in the use of Earth Observation data and tackle the Sustainable Development Goals.

This was a staff-led extra-curricular challenge for students. At the GEOSS/HACK Space Hackathon there were 6 challenges that the participants could decide to undertake. Sourcing these challenges was very work-intensive. The challenges that were set to participants were as follows:

a. Designing for Accessibility - Make an application that maps accessibility information and allows the users to add new information about cities and points of interest.
b. Cloud Detection Game - Increasing the amount of classified data for machine learning. The goal is to develop a game where the player classifies Sentinel-2 image pixels.
c. Astro-ecology - Saving Earth's biodiversity. A key part of the system was developing software to automatically detect and identify animals and humans in aerial thermal video footage.
d. Connecting Arctic voices - Develop a tool to allow young people living in the Arctic to engage with satellite images, weather data and in-situ observations in new ways, to promote sharing of information with their Elders and help to identify data that could be used to predict environmental hazards.
e. Protecting the Forest - Develop a biodiversity monitoring tool to motivate local patrols in Madagascar to engage with satellite images and encourage them to contribute in-situ observations.
f. Understanding Child Malnutrition in Sudan using Geographical Data.

The hackathon was held at ESRIN’s headquarters in Frascati, Italy as well as being streamed to ESTEC in the Netherlands and ECSAT in the UK. At the end of the challenge, all participants were asked to present a 2-minute video, uploaded to YouTube, explaining their application plus

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a small description of their solution together with their code on Github. The winning team were given prizes.

VIII. Micrometeoroid Impact, Damage and Shielding Activity – The Open University

The Open University run a curricular activity on impact damage and shielding of micrometeoroids using a remotely operated optical microscope. The Micrometeoroid Damage Equations are used to estimate the crater depth or maximum thickness of material that will be perforated by an impactor on a surface. The activity can be conducted with the microscope itself or using provided measurement data. The activity is intended for independent study and takes students roughly 3 hours to complete.

The activity is part of a space science module taught at the Open University as part of the MSc 'Space Science and Technology' programme. The activity is run through the Open STEM Labs (OSL) - a platform bringing interactive practical science to distance-learning students through the internet. Some OSL activities are open to all, some are restricted (see http://stem.open.ac.uk/study/openstem-labs).

Micrometeoroids present a hazard to spacecraft and astronauts. Cratering events occur at hypervelocity i.e. greater than speed of sound in the target material. The purpose of the case study is to highlight the importance of designing for damage mitigation from micrometeoroids. Students investigate the effects of micrometeoroid impact of different sizes on spacecraft materials and a method for reducing the mass of protective shielding. The remote optical microscope gives students the opportunity to engage practically with the subject.

This was a staff-led curricular activity with a focus on student independent learning. The optical microscope can be used to measure the dimensions of the impact crater [Note: This is an optional step as a data sheet is provided with all the measurement results]. The activity sheet contains several problem questions to answer, using data obtained from the remote optical microscope. Answers are provided for the students to assess their understanding.

IX. Water rocket competition – University of Bristol

Based on a suggestion by Kingston University London, who run this as a curricular competition, Bristol SEDS ran a water rocket competition in October 2017 with the aim to have multiple teams competing to design and build water rockets. 5 teams of 3-4 students competed, each producing a design and building a rocket to carry an egg payload and then launched their rockets, once on a test launch day and once again on the competition day.

A water rocket is a simple and safe way of demonstrating the principles behind rocket propulsion. The competition aimed to get teams of students to design the nose cone, tail fins of a pressure vessel, a 2-litre fizzy drink bottle. The teams would have to be able to design, build and launch and recover their water rocket carrying an egg payload and achieve the highest possible altitude, and perform both these tasks repeatably. The rocket is partly filled with water and pressurised using a pump while attached to a "multi angle Full Bore launcher". Once ready for lift-off, a launch pin is pulled out from the launcher and the rocket is propelled into the air. The rocket needs a parachute that will deploy at max altitude and allow the rocket to be recovered. The objective was to have fun, develop teamwork, design iteration and manufacturing skills.

The process for organising the competition was:

1. Present project to society, organise teams, hand out documentation on how to build water rockets (http://www.npl.co.uk/upload/pdf/wr_booklet_print.pdf)
2. Provide resources / set maximum budget that teams can use for buying resources
3. Run workshop / assistance sessions twice a week
4. Run a test launch weekend
5. Run final launch weekend
6. Judge competition
7. Run final presentation

X. Project Sunride - Nova Rocket Innovation Design Engineering - University of Sheffield

Project SunrIde was the first student-led rocket design engineering team from the UK to compete in the Spaceport America Cup (SAC) https://www.spaceportamericacup.com/. in 2018. This is held in Las Cruces, New Mexico and the team competed in the 10,000ft category solid propellant commercial off-the-shelf motor (COTS) competition. The team had to design and manufacture a sounding rocket, which they named 'AMY', after Britain's first aviator and alumna of the university, Amy Johnson. In this competition round, rocket "AMY" (Friday 22nd June 2018) reached an apogee of 10,017ft and team SunrIde won the prestigious James Barrowman Award for Flight Dynamics, beating more than 140 university teams from the USA, Canada, Europe and Asia. In 2019, the success of the University of Sheffield inspired three more universities from the UK (Bath University, Cranfield University and Open University) to participate in SAC. The SunrIde team successfully built and launched a completely in-house rocket "HELEN" named after the University of Sheffield alumna Helen Sharman - the British astronaut. The SunrIde launch (Friday 21st June 2019) beat the UK's 19 year long standing national altitude record. HELEN reached an apogee 36762 ft, with a top speed of 2.67 Mach in just 4 seconds and acceleration of 29G.

SunrIde is part of Sheffield Space Initiative (SSI). Since the project's inception in 2017, SunrIde was formed by academics from the Automatic Controls and Systems Engineering (ACSE) and Mathematics and Statistics

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Departments of the University of Sheffield. Now, alongside from SunrIde, SSI consists of four more exciting space related projects, i.e. the Sheffield University Nova Balloon Lifted Solar Telescope, MarsWorks, Avalon ROV and the Sheffield University Nova Satellite.

SunrIde consisted of Undergraduate and Masters' students across the Faculty of Engineering (ACSE, MecEng, EEE, BioEng, Material Science, Aerospace), Faculty of Science and students from Hallam University. The team composed of 5 research sub-teams: Design and Propulsion, Recovery Systems, Avionics, Payload, Structures and Manufacturing and 1 back-office subteam on Media.

Without any prior experience in rocketry, building a high-power rocket from scratch proved to be a daunting task. The team had to rely on their communication skills in order to bring students from different engineering backgrounds together. A network of experts in academia and industry was established in order to develop the overall concept and provide support throughout.

XI. Drop your thesis– University of Cranfield

Cranfield University supported a successful application to the European Space Agency (ESA) 'Drop your Thesis' (https://www.esa.int/Education/Drop_Your_Thesis/) competition. In this competition, selected groups of students have the opportunity to conduct their final experiment in the 146m ZARM Drop Tower in Bremen where gravity levels of 10^{-6}g can be achieved. Two different modes exist for the experiment, the drop mode (4.74 seconds of microgravity) and the catapult mode (9 seconds of microgravity).

The Cranfield 'Land 3U' microgravity experiment sought to quantify the energy dissipation during touchdown on low-gravity bodies, such as asteroids, to explain the apparent disagreement between low energy dissipation measured during touchdowns on Philae (ESA) and Hayabusa (JAXA) and the very high energy dissipation measured by previous experiments in microgravity.

This was a PhD student and academic supervisor-led curricular activity. The group was made up of 5 MSc students from Cranfield University's 'Astronautics and Space Engineering' course and 1 PhD student. The Land 3U team's experiment focused on Unpowered CubeSat Landing for Asteroids. The ZARM Drop tower was ideally suited to simulate this microgravity environment, encountered by small asteroids approximately 100m diameter. The 1U CubeSat mock-up structure mimicked a 3U landing (~3 kg) with a velocity of 100 to 200 mm/s. The velocities before and after the touchdown were recorded enabling calculation of the ratio of linear momentum loss (the coefficient of restitution, "ε"). These calculated values allowed the energy dissipation to be quantified.

In some cases, it is possible for the teams to use special equipment (e.g. CCD cameras, heating/cooling devices) available from the drop tower operator. These are assessed on a case-by-case basis and may carry associated costs for the team. The Education Drop Tower Campaign was a 2-week long campaign in October-November in Bremen, Germany. The first week is dedicated to integration and ground testing of the equipment. In the second week, the team is allocated 5 launch opportunities for the experiment. The students were able to submit a paper to a conference to report on their findings.

XII. Conclusions

The Space Universities Network is a community of space science and engineering Higher Education staff at UK Universities. This network has collected 10 case studies from different Universities around the UK to share good practice and motivate students to join the space industry. Further details of the case studies can be found at https://spaceuniversitiesnetwork.ac.uk/resource-bank/case-studies. It is hoped that staff and students from other institutions may benefit from this collection of recipes for learning about space.

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