Establishing Thriving University-Level Space Education

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Abstract
Recent analyses of the UK National Space Strategy [1], Space Sector Skills Survey [2] and The 2020 Space Census [3], have investigated and highlighted many of the established strengths and weaknesses of the current UK Space Sector and the role of training and educational programs supporting it. Furthermore, there is additional research into what self-reported roadblocks early career students and workers (and employers) consider important in this journey [4]. Academia, employers, schools, colleges, and museums all have considerable roles to play in shaping the future science capital of our populace and establishing people on the tech workforce pipeline. Rising to meet this challenge, The University of Nottingham wants to develop the UK's space workforce and is proud to have begun its first dedicated aerospace undergraduate course in 2016. In addition to the core lecture modules, added project experience is available in the form of group and individual supervised projects. These practical activities are a rare opportunity to learn unique space skills and work hands-on with spacecraft technology, something in short supply in the UK at the undergraduate level [2]. The practical, hands-on components are an important part of the space education programme and involve different platforms and projects going from simple electronics workshops to CanSats, FlatSats and experimental Rockets.

These activities culminate in the CubeSat Program: a student-led group of projects to develop, build and fly CubeSat missions with a variety of payloads. The students have the possibility to present their own mission idea or join existing ones of interest to the research community. To support these high-fidelity opportunities for students and early career workers, a permanent on-site COTS Ground Station will serve as a control center for all these student-built satellite missions. To help with the establishment of this facility, The University of Nottingham has been cooperating with the local amateur radio community to train and license the student team.

This paper deals with the description of the different projects and presents the University's point of view about the strengths and weaknesses of our Space educational programme.

Keywords
Space Education, CubeSats, Hands-On Activities.

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Acronyms/Abbreviations:

ADCS	*Attitude Determination and Control System*
AITV	*Assembly Integration Test and Verification*
COTS	*Commercial Off The Shelf*
M3	*Department of Mechanical, Materials and Manufacturing Engineering*
GS	*Ground Station*
GNSS	*Global Navigation Satellite System*
HWIL	*Hardware In the Loop*
UnB	*University of Brasilia*
UoN	*University of Nottingham*

1. Introduction

Hands-on education and students' engagement are two vital aspects of The University of Nottingham (UoN) Space program. The program is part of the Aerospace Course established in 2016 and offering four different courses at both BEng and MEng levels. As evident in the space sector, interdisciplinary learning and collaboration as at the heart of a successful project. Hence the University and supporting staff are actively supporting the growth of space related teaching and extra-curricular projects to other interested technical departments and research groups, with the hope that their students will be excited to take part too.

This paper details some of the many ways UoN is supporting and encouraging its student training for careers in the space sector. It accompanies other publications at SSEA 2022 from the students themselves which describe their own views and educational achievements. Through formalizing University support for these programmes through official student societies, research groups, teaching and project based accredited modules, UoN hopes to improve the student experience and quality of their learning.

2. Facilities

Since 2019, and despite the pandemic, The University of Nottingham was able to establish and acquire new important facilities for learning and teaching space related activities. All the facilities are in the main University Park Campus in the so-called "Scientific area" and are accessible to all the students from different departments and faculties. The following sections summarise facilities available at UoN.

2.1. NottsSpace Lab

Opened in January 2022, this workspace is available to students for teaching and practical work. This area is used for different purposes: an office for students that are involved in PGR research related to CubeSats and small satellite, as a classroom for the practical workshops in different modules, and as a dedicated workspace for students and staff that contribute regularly to CubeSat design, construction, testing and mission operations. This well-equipped lab shall soon have all the proper equipment and simulators for building and testing small satellites.

The ability of using a permanent workspace has already improved the productivity and networking capabilities for the space program and provided a fantastic opportunity to showcase UoN's capabilities in space education; attracting new students during open days and other events open to the external public.

It also encourages further opportunities for teaching workshops for various groups to be led in the room using well-known equipment and facilities - and permanent staff.

2.2. Satellite Ground Control Center

A commercial off the shelf (COTS) ground station (GS) kit was acquired from Alen Space and is currently being installed on a roof at the main Nottingham campus. It will provide transceiver radio links with UHF, VHF and (receiving only) S-band channels.

The GS equipment, can be remotely controlled from any authorized UoN computer. All the students are encouraged to use the facilities and develop their practical skills in radiocommunications through supported training sessions. These include official courses conducted by the local radio amateur radio club, which is also an active partner of the space educational activities at UoN, as described later in the paper.

Licensed students, authorized by national OfCom laws to transmit and receive radio signal, are provided with a specific userID (callsign) and password that allow them to access the facilities from their personal computer and acquire data from orbiting satellites.

For the ones that are not yet authorized (hence unlicensed) there is the possibility to learn how to track and receive a satellite during dedicated practical lectures, extracurricular and outreach activities.

2.3. *Attitude Determination and Control System (ADCS) Simulator*

The University of Nottingham Space team is putting particular attention on teaching aspects related to the design, manufacturing, and testing of new ADCS hardware and software. To achieve this important goal the team decided to develop an in-house Helmholtz cage and air bearing table.

The equipment, which is being designed and manufactured by students as part of their credited module projects, is going to be installed at the end of spring semester 2022. The 2.5 m Helmholtz cage has a 3-axis square coils configuration and simulates Earth's magnetic field automatically at different altitudes.

The air bearing table can support single ADCS components or an entire satellite up to a 3U CubeSat within the Helmholtz cage.

The two systems in combination will be used to perform Hardware in the loop (HWIL) tests of ADCS Hardware and software developed by students at UoN, for example a 3-axis magnetotorquer solution for CubeSats designed this year by a BEng student. In addition, the testbed will be used to develop new lines of research in cooperation with national and international experts on the area.

2.4. *Satellite simulators and software*

As part of teaching activities, UoN staff now have the opportunity to use dedicated simulators to show the specific use of satellite subsystems or how to integrate a payload inside a real satellite bus using flight model equipment.

In 2019 the Department of Mechanical, Materials and Manufacturing Engineering (M3) acquired a commercial 1U CubeSat simulator developed by Theia Space [4]. The system is extremely useful for showing the students the functionalities of different subsystems, neatly packed within a complete 1U satellite including reaction wheel and magnetorquers. In addition, the university has also procured ground support equipment including a Sun simulator, a low-friction rotating platform, and a simple Earth magnetic field simulator based on two permanent magnets. The simulator kits are used as teaching tools for practical lectures in the lab but are accessible to student groups for self-studying sessions and extra-curricular projects to improve their knowledge of subsystem interfaces.

Another 3U simulator provided by OpenCosmos is also available in M3 and used by students to investigate the possibility to integrate their own payload in a commercial satellite bus.

Following the first student-led attempts at CubeSat avionics integration (section 4.2), members of NottsSpace team and M3 staff members decided to develop their own training workshops and kits to introduce skills related to hands-on space project assembly, integration, testing and verification. Several COTS components such as microcontrollers, cameras, battery packs, sensors and radios, have been procured in order to prepare different educational kits called "FlatSat". These kits, are being used to teach microcontroller electronics and coding skills, with specific application and examples to how they're used in spacecraft. The components are assembled with breadboards and jumpers to replicate the avionics of more sophisticated satellites and are used in taught laboratory workshops and outreach events for the University. Students follow instructions to integrate the parts and complete pieces of code to enable basic functionalities typical of a satellite mission, such as taking temperature readings and send it through radio beacon to the local ground station. This solution has proven quite effective at levering up the enthusiasm of the students, while providing the rare chance to do space specific laboratory work – a key theme of UoN space teaching.

For developing software skills, M3 students have access to a series of platforms that allow them to simulate, analyse and operate satellite mission from the scratch. The most used software are: MatLab, Catia 3DExperienece, SolidWorks, Ansys, Abaqus, Orbitron, BeeApp, FreeFlyer. The use of the software is taught during different modules lectures but also during specific intensive courses. Similar to the FlatSat workshop, other PGR involved in teaching and space project development have created a suite of student-accessible software that is used for the design and analysis of CubeSat missions. Through several workshops, students are taught to develop such simulations themselves, for applications ranging from attitude control and orbital manoeuvres, to satellite telecommunications

2.5. *Manufacturing Facilities*

For manufacturing, University of Nottingham offers students free access to facilities with rapid prototyping with 3D printers, and different types of machining such as Milling, CNC turning, Electric discharge machining wire erosion, manual arc welding, material cutting, and metal fabrication, among others.

3. Collaborations

One of the key aspects of the space educational activities at UoN is to establish and promote internal and external collaborations. Space sector products naturally require understanding that the design is complex, requiring different expertise and extremely close, interdependent teamwork. Hence, establishing cooperation with different departments, faculties or with companies and other research centers opens up new possibilities and perspectives.

3.1. Internal Collaborations

Hands-on space activities at UoN are managed involving different experts inside the aerospace course, M3 Department and Faculty of Engineering. The CubeSat program also involves experts from other Faculties and research teams. Thanks to the support from these groups, the products developed by the student team can be developed according to requirements from these specific "customers" for science payloads. The students learn how to deal with product development alongside managing requests and expectations from the customers, as well as the rest of their team. At the same time, being a student directed mission, it also gives them the opportunity to develop their own innovative ideas and research. A practical example of this approach is the close collaboration with the Astropharmacy & Astromedicine Research Group at UoN. Because of the support and motivation from the interdisciplinary space community at UoN, two student CubeSat projects are currently in progress (WormSail & AstroJam). The team is also continuing to establish new collaborations in area including Geospatial research, Additive Manufacturing, Advanced Materials, Computer Science and, in the near future, hopes to develop links with the world class research from the UoN Rights Lab.

By integrating the CubeSat programme into the wider UoN network, the team gains beneficial access to additional facilities. The laboratory spaces at the School of Pharmacy, for example, include COTS incubators, instruments such as microscopes and fluorescent spectrometers (for controls), and vacuum chambers. There are also ultrasonic vibration cleaning instruments, although as these are intended for pharmaceutical apparatus it is not recommended, they be used for spacecraft parts cleaning. The Nottingham Geospatial Institute (NGI) leads the satellite navigation and positioning systems activities. Hardware-based and software-based Global Navigation Satellite System (GNSS) simulators have become available such as the Orolia (Skydel) GSG-8, used for RF front end validation. There are anechoic chamber facilities available at UoN, and instruments including spectrum analyzers, that can be used for TT&C testing of ground and space segments. Several shakers for structural tests and material characterizations are also available and accessible for the student projects.

3.2. External Collaborations

External collaborations mostly are with new space economy companies and start-ups, that have the dual aspect of offering new area of development and research but also the possibilities for the students to learn about the business approach used during industrial projects. Actually, the group is cooperating closely with an SME but in the near future the idea is to implement collaboration with big industrial players. Since the course and the activities are quite new, the team is aware that its capabilities should be proven before the big players can be attracted to cooperate with a new team. Considering the actual cooperation, collaborative projects are mainly devoted on the design and analysis of feasibilities studies dedicated to the confirmation that specific, novel technologies can be applied in space. These are mostly developed during individual projects with a duration of less than one year.

Another fruitful external cooperation, established in 2020, is the one with South Notts Amateur Radio Club (SNARC). The club, located in Nottingham, actively support the NottsSpace team offering students extra training. This extra training has not only complimented their studies on radio and electronics technology but helped them pass their Radio Society of Great Britain exams so they can legally operate the UoN ground station. SNARC's expertise is supporting the inclusion of new TT&C technologies to the CubeSat and the CanSat project.

3.3. International Collaborations

In terms of international collaborations, the space program at University of Nottingham has already a solid network, that of course UoN aims to expand and grow.

NottsSpace is working elbow to elbow with University of Brasilia (UnB), in Brazil. Not only the two universities have twin GS and similar facilities but are closely cooperating in project such as Alphacrux, WormSail and AstroJam. The two teams are cooperating through sharing educational material and methods, and

comparing the results obtained in order to better support their students and space projects.

In Brazil, UoN is cooperating also with INPE, the Brazilian National Space Research Institute, to develop new satellite missions such as RaioSat and supporting, as free consultancy, the UbaTubaSat II mission. That mission also involves students from the public secondary school Tancredo I, located in UbaTuba (SP).

In Europe the team is actively collaborating with University of Beira Interior in Covilha and University of Oporto, both in Portugal. This collaboration also involves a local SME and startup in a project called Antaeus, described later.

4. Projects

UoN has established a series of projects in the last 4 years dedicated to the direct involvement of the students in real space projects. The hands-on experience is priceless and give them a unique opportunity to realize something that will be operative. In the first two years a lot of effort has been focussed on finalizing collaborations and procuring dedicated spaces to develop the real missions. In the preliminary phases simple projects such as PocketQubes and high-altitude balloons have been developed up to the engineering model design stage. However, at the end of 2020, the possibility to get a real launch opportunity and with some supporting funds available, gave a real push to establish a more organized and consistent student space program. From this and the students commitment to formalise the projects for a better, wider involvement, the development of a student space society (SpaceSoc) and its project based arm (NottsSpace) was born. In the following sections some of the active complete projects are presented.

4.1. AstroJam

AstroJam is a 3U multipayload CubeSat mission designed and lead by UoN students, with payloads from the Nottingham Geospatial Institute and the Astropharmacy Research Group. The project is currently under evaluation for the 4th European Space Agency Fly Your Satellite competition. The core team is composed by PhD, MEng and BEng students from different faculties and departments such as M3, Astropharmacy and Computer Science and is expanding to involve students from other departments and faculties.

4.2. Wormsail

WormSail is a collaborative project between the University of Nottingham and University of Brasilia, with the aim to design, build and fly a small CubeSat to conduct experiments in space. These experiments include everything from the behaviour of tiny nematodes, to using the Earth's magnetic field to steer the satellite and more. Once it's launched, it could be the world's first set of multi-cellular organisms on a CubeSat flight. Work began on WormSail in September 2020 and is currently ongoing as of 2022.

4.3. TemboSat

TemboSat is a mission proposed by third-year Mechanical Engineering students for their Group Design and Make module project. The mission's aim is to use CubeSats to track elephants in the wild and help reduce their poaching through providing local authorities up-to-date elephants' locations.

4.4. CC4CC

CC4CC (CubeSat Constellation for Climate Changes) is a collaborative project conducted with GSL Venture and EnduroSat. The project was firstly proposed by a BEng student [6] and aims to investigate sea level rising using a constellation of satellites. The mission design and analysis and the definition of the bus systems is the responsibility of UoN students.

4.5. Antaeus

Antaeus [7] is the acronym for Astrophysical Nanosatellite for Technological Advancement and high-Energy Universe Studies. It is a collaborative project between the University of Nottingham, University of Beira Interior and University of Oporto, with the aim of in-orbit demonstration of the use of a new high energy detector developed by University of Oporto. The UoN students will have the opportunity to cooperate with their colleagues from Portugal and at the same time be responsible for crucial subsystems such as the Structure and the TT&C.

4.6. RaioSat

RaioSat [8] is a satellite proposed by INPE and designed in collaboration with NottsSpace. The project has the aim of predicting severe weather phenomena using a Lightning Flashes Detection system developed by INPE and its

partners. UoN's role is to act as the systems engineering team, developing the bus and taking care of all the AITV phases.

4.7. CanSat

In July of 2021, students took part in a CanSat competition that involved the design and development of a satellite mission. The mission was assessed through design reviews following ESA Standard Project Management and were presented to UK Launch Services Ltd (UKLSL) and OneWeb judges. The CanSat was designed to be launched using a small-sounding rocket up to 450 meters. Once ejected it was recovered using a recovery system based on a parachute. The team was part of the "Peake CanSat Category" which used a 66mm diameter and 160mm tall CanSat. The proposed mission was to collect air pollution data around the launch site, and record and track the flight path in real-time. The team was awarded with the second prize in their category in 2021 during the Mach-21 competition. A new mission is under development to compete at the MACH22 competition with the launch scheduled in July 2022.

4.8. Small Rockets

The UoN is also active in the design and test of model rockets. Following the interest and enthusiasm of the students from CanSat and CubeSat missions, in 2022 funding was allocated to support their extra-curricular activities and their participation in student competitions. This year they have been selected to attend the Mach-22 competition organised by UKLSL (UK Launch Services Ltd) and UKSEDS (the National Student Space Society). During the competition teams have to design, manufacture and launch a model rocket to achieve an altitude as close to 1km as possible, and deploy a CanSat (upgraded from the Mach-21 entry). The team would gather data from the launch, such as measuring and transmitting altitude, inertia and position during flight and recovery to a ground station.

5. Conclusions

In just a few short years, UoN has built a thriving space educational program, thanks to the involvement and enthusiasm of its staff, students, and collaborators. From its first few simple projects, it has grown and organized to support a wide-range of student led groups and research topics, while including plenty of teaching elements and laboratories – some of which are designed and run by the students themselves!. The authors hope the lessons and examples presented in this paper are of interest and use to students and staff elsewhere in the world, also hoping to promote space as a fantastic opportunity for technical education, and an important part of future global science economy, infrastructure, and diplomacy.

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