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Multidisciplinary Space Education in a Blended Learning Environment: the New Spaceflight Minor at Delft University of Technology

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Abstract

Driven by wide interest among TU Delft (Delft University of Technology) students to acquire focussed knowledge on space engineering, missions and planetary exploration, a new spaceflight minor was developed for the minor program of the university. With its minor program, TU Delft affords its students an opportunity to dedicate the first semester of their 3rd BSc year to a set of courses chosen among the numerous options offered specifically by the TU Delft or another university. Students are not only allowed but encouraged to explore topics and study fields outside their main BSc track.

The spaceflight minor is designed as a multidisciplinary, thematic program, in which the students gain insight in the demand for space applications, mission analysis, system requirements and sizing. This multidisciplinary setup is facilitated by the recently established TU Delft Space Institute (DSI), of which all the faculties involved in the minor are members. The minor and the DSI provide a unique opportunity to strengthen space education and research across TU Delft.

The minor covers two quarters of the academic year, spanning twenty weeks, and includes six courses. Offered in the first quarter are: Introduction to Spaceflight (for students without Aerospace Engineering background) or Electronic Circuits (for the other students); Space Exploration, with basics and examples of planetary and astronomical exploration and an introduction to space law; Earth Observation, covering basics of remote sensing of the Earth. The second quarter includes: Spacecraft Technology, providing an overview of the technology of spacecraft subsystems with emphasis on small satellites; Satellite Tracking & Communication, on telecommunications, ground station operations and telemetry analysis from a theoretical and practical point of view; Spaceflight Assignment, the final project in which students produce real, small-scale space deliverables, and reflect on the process and results of development and analysis in the complex space engineering and scientific environment. In total, 15 lecturers from three TU Delft faculties and one from Leiden University contributed to the minor. Many of the courses employ innovative education techniques, such as flipped classrooms and videos produced by the lecturers. Some courses are simultaneously offered to campus students and external participants in a full online format.

The first edition of the minor, delivered from September 2015 to January 2016 to 44 students from various TU Delft faculties, can be considered a success with excellent feedback from participants. The paper elaborates on the minor design and learning objectives, showing how multidisciplinary, innovative education can be effectively implemented for students with different academic backgrounds.
Keywords: education, spaceflight, multidisciplinary

Acronyms/Abbreviations

Mechanical, Maritime & Materials Engineering (3ME), Aerospace Engineering (AE), Applied Sciences (AS), Civil Engineering & Geosciences (CEG), Delft Space Institute (DSI) [1], European Credit Transfer and Accumulation System (ECTS), Electrical Engineering, Mathematics and Computer Science (EEMCS), European Space Agency (ESA) [3], Global Navigation Satellite System (GNSS), Indian Space Research Organisation (ISRO) [4], National Aeronautics and Space Administration (NASA) [5], Space Launch System (SLS), Technische Universiteit (TU)

1. Introduction

Spaceflight activities require the collaboration between professionals from a wide array of disciplines, yet the number of programs designed for students from such a broad set of disciplines is limited. Nevertheless, broad interest by students of many technical disciplines has been on the rise, no doubt influenced by the increasingly visible progress being made in space on various fronts: ESA's Rosetta asteroid and landing mission [6], NASA's progress on SLS and Orion vehicles [7], ISRO's Mars Orbiter Mission [8], NASA Kepler spacecraft's confirmation of over 2,300 exoplanets [9], SpaceX's commercial development and operation of the Falcon launch vehicles and Dragon crew module [10], as well as TU Delft's own success with the Delfi cubesats of the TU Delft small satellite program [11], to name but a few. Given this growing student interest in spaceflight and the demand for expertise from numerous technical disciplines, TU Delft (Delft University of Technology) developed a spaceflight minor.

2. Key features of the minor

The objective of the minor is to allow students from various engineering backgrounds to rapidly gain an overview of the spaceflight arena and insight into a number of topics prominent in today's space activities. The diversity of topics in the minor is therefore a prominent feature, from space engineering fundamentals through mission analysis, space systems requirements and space applications.

A number of other features characterize the minor. As reflected in the diversity of topics covered, the minor was also designed not merely to accommodate but to emphasize the multidisciplinary nature of spaceflight activities. Given the great spread of disciplines required to carry a space mission to completion, the minor was similarly designed to incorporate students from many different technical backgrounds. Indeed, the initiative to develop the minor, and the multidisciplinary setup, is aligned with the aims of the TU Delft Space Institute (DSI), of which all the TU Delft faculties contributing to the minor are members. In total, 15 lecturers from three TU Delft faculties, and one from Leiden University focused on space law, contributed to the minor.

The diversity of topics and the strong multidisciplinary population of both students and lecturers is further bolstered by the use of innovative educational techniques and working styles, such as flipped classrooms, videos produced by the lecturers and discussion forums. Some courses are simultaneously offered to campus students and external participants in a full online format. As is the case for all courses given in the Faculty of Aerospace Engineering and increasingly across TU Delft, the language of instruction is English, reflecting the diverse and international student and lecturer population. The following overview of the minor, followed by a description of each of the course modules, provides more detail regarding the content and delivery of the program.

3. Overview of the minor

The spaceflight minor was developed within the context of the minor program of TU Delft. In the first semester of their third year of bachelor studies, students focus exclusively on a minor (including minors offered by other universities) and earn 30 ECTS in the process. In the minor structure, students are encouraged to explore topics and study fields outside their main BSc discipline. The spaceflight minor was followed by both aerospace and non-aerospace engineering students.

The first edition of the minor was delivered from September 2015 to January 2016 to 44 students from five TU Delft faculties. (Note that the cap of 50 enrolled students was met, but administrative difficulties with the enrollment waiting list resulted in 44 enrolled students). It covers two academic quarters over twenty weeks and includes six course modules (see Fig. 1).

Offered in the first quarter are: Introduction to Spaceflight (for students without Aerospace Engineering background) or Electronic Circuits (for the Aerospace Engineering students); Space Exploration, with basics and examples of planetary and astronomical exploration and an introduction to space law; Earth Observation, covering basics of remote sensing of the Earth.

The second quarter includes: Spacecraft Technology, providing an overview of the technology of spacecraft subsystems with emphasis on small satellites; Satellite Tracking & Communication, which focuses on telecommunications, ground station operations and telemetry analysis from a theoretical and practical point of view; Spaceflight Assignment, the final project in which students produce real, small-scale space deliverables, and reflect on the process and results of development and analysis in the complex space engineering and scientific environment.

The Introduction to Spaceflight and Electronic Circuits course modules create a common knowledge base for students with backgrounds in different disciplines, thus enabling closer collaboration in the remaining modules. Each of the seven modules is described below to provide greater detail on their content, setup and execution.

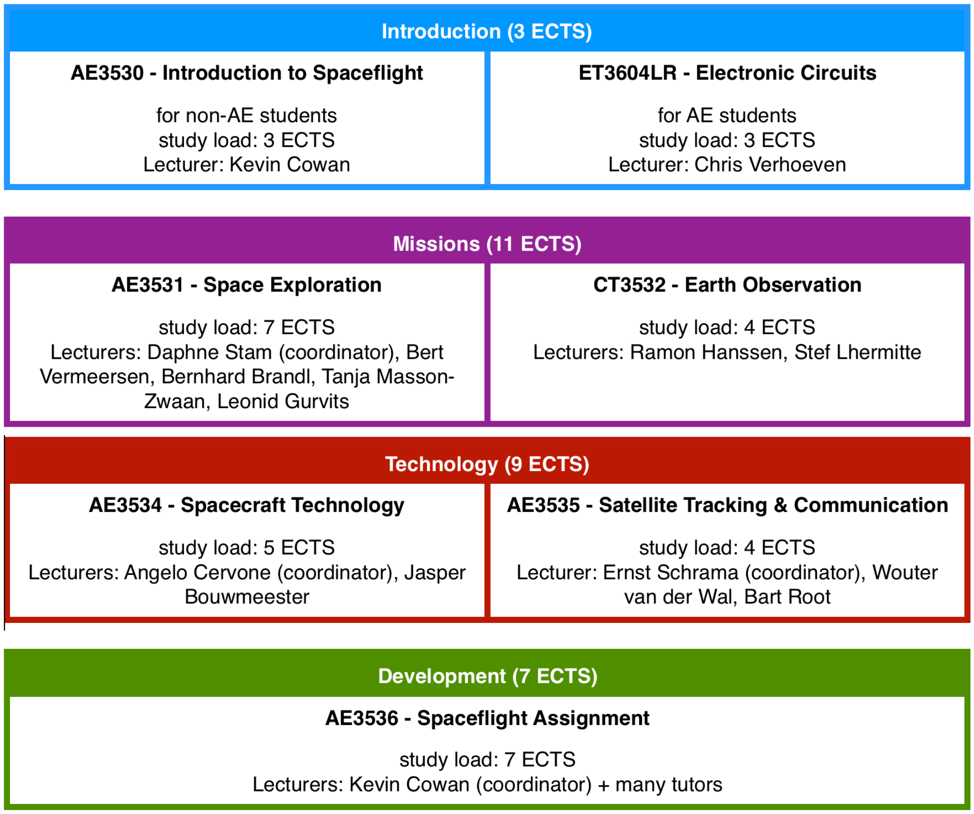

Fig. 1 Overview of the spaceflight minor structure

4. Course module descriptions

4.1. Introduction to Spaceflight

This course module is provided to the non-aerospace engineering students to ground them in the essentials of spaceflight. At completion the students are conversant in key areas, such as propulsion, astrodynamics, spacecraft subsystems, and the space environment. They are able to compute first-order mission parameters, relate them to mission characteristics, and have meaningful discussions with their aerospace colleagues.

Lectures are provided on video and augmented through weekly working sessions where individual and collaborative exercises are tackled and discussion is encouraged. A flipped classroom structure is employed, and textbook exercises are supplemented with optional calculation challenges using supplied or student-written programming code. The course is simultaneously run as an online course, and the online and on-campus students are encouraged to build a common learning community through an online forum. Assessment occurs during a written exam.

4.2. Electronic circuits

Modern spacecraft without electronics are unthinkable, so the spaceflight practitioner must have at least a basic knowledge of electronic systems. This course module provides Aerospace Engineering students with introductory knowledge of electronics, enabling them to converse with electrical engineers, comprehend the technical terms used and read circuit diagrams. Students study fundamentals such as the relation between voltage, current, and power, tackle signals as a time and spectral phenomenon, and become acquainted with signal processing functions. They also learn about impedances and networks, semiconductor components, analog electronic circuits, and power supplies. Furthermore, they are introduced, via a practical laboratory exercise, to construction and measurement techniques and the issues that can arise from physical phenomena.

Classroom lectures, in-class assignments, and a laboratory exercise are used to deliver the material. TU Delft's Delfi-C3 satellite is used as a demonstration specimen to discuss satellite design and operation.

4.3. Space Exploration

This course module examines the scientific rationale for studying the solar system, stars, galaxies, and the universe, and the connection with the design and implementation of scientific space missions. Students acquire a broad overview of the current level of knowledge on the physical properties of planets, other bodies and environments in the Solar System and beyond. Additionally, they develop insight into the scientific and technical requirements for remote-sensing and in-situ space missions in part through hands-on experience analyzing different types of observational data.

The module is structured with four components: planetary exploration (36%), astronomical exploration (43%), a close-up of a planetary mission (14%), and space law (7%), where the relative assessment weights are indicated. Planetary exploration deals with a huge range of physical properties of planets and other bodies (eg. asteroids, comets) in the Solar System and beyond, enabling the student to understand their formation and evolution and to gain insight into how this knowledge was obtained. Astronomical exploration conveys the structure and evolution of our universe, the stars and other objects within it; students develop an understanding of the observational tools and physical processes which allow them to derive masses, ages and other properties of stars and galaxies.

In the close-up of the planetary mission which is in development, researchers that are directly involved in a current mission (in 2015-2016 the mission was ESA's JUICE mission that will be launched in 2024) provide students insight into the practical aspects of mission development, including the rationale for choices and decisions that are made. Finally, the space law component enables students to apply the general principles of space law to space exploration mission cases.

This module is delivered via classroom lectures, and the following assessment methods are employed: homework, a written report, case study preparation and defense, and a written exam (only for the astronomical exploration part). The written report covers a practical component in which students conduct an initial analysis of available observations of, for example, planetary radiation using pre-existing code.

4.4. Earth Observation

This course module is focused on two facets of the observation of our home planet from space: "signals": the planetary processes or parameters to be observed or monitored, and the "systems": the requirements that these signals pose on the space infrastructure, the orbits, the instruments, and the data processing methods.

Topics investigated include Earth's potential fields (gravity and magnetics) and electromagnetic fields and cover the regions: hydrosphere, atmosphere, biosphere, cryosphere, anthroposphere, lithosphere, mesosphere and core. Spatial, temporal, spectral and radiometric sampling are introduced to relate observational parameters to measurements.

The learning objectives enable the student to: identify earth observation systems and relate them to mission, system and spacecraft requirements, characterize various signals in terms of observable parameters, and explain fundamental principles of the main observation techniques. Instruction is delivered through classroom lectures and supported by exercises. Assessment is effected via a written exam (70%) and a presentation (30%) on a student-designed Earth observation mission.

4.5. Spacecraft Technology

This course module deals with the technologies and subsystems of spacecraft. The learning objectives focus on the technical principles of these spacecraft, enabling students to identify technology state-of-the-art, available subsystem options at a component level and their technical limitations. Students also characterize key performance parameters of different spacecraft subsystems and assess the difference between theoretical predictions and real-life values.

The module is structured with three components: Satellite Bus Platform (40%), Rocket & Onboard Propulsion (40%), and a CubeSat Design Workshop (20%). The first two components are assessed via a written exam, and the workshop culminates in a report, which is assessed together with the work executed.

Lectures are provided on video, and classroom tutorials are held to discuss the material and exercises as well as refine students' understanding. Students were additionally required to contribute a written article to a community "wiki" which, for the Satellite Bus Platform component, would augment the topics already covered, and for the Propulsion component, would create a database of propulsion engines.

This course, including the workshop component, is also offered in an online format via the TU Delft's online learning platform [12], and interaction between on-campus and online students was encouraged via an online forum.

4.6. Satellite Tracking & Communications

This module consists of four components in which the communication between ground systems and satellites as well as ground-based satellite tracking are treated. First, the space communications component familiarizes the student with communications hardware, software and techniques for receiving, storing, and transmitting data. Topics range, for example, from modulation techniques, signal and antenna properties, and dataflow mapping to the ramifications for bandwidth and data storage. Second, in the space communications practical component, students assemble a microcontroller board and transceiver experiment in order to examine communication protocols, a simulated ground station satellite link and datalink performance. Third, in the operations practical component, radio equipment and tracking software are used to track a satellite and analyze the tracking performance of the ground setup using gathered tracking data, signal properties, the link budget and pass predictions. Finally, in the telemetry analysis component, students derive satellite properties such as position and attitude from observed carrier frequency and telemetry data, respectively, and relate the tracking data to scientific applications.

Instruction includes both classroom and video lectures, as well as problem-driven exercises, in addition to the guided practicals. Assessment for operations and telemetry components of the module is done via an exam as well as homework assignments whereas the two practical components are assessed via reports on the results obtained. Reports are checked with the turnitin [13] plagiarism feedback system.

4.7. Spaceflight Assignment

In keeping with the design philosophy behind the spaceflight minor, the spaceflight assignment module aims to place the student as close to "real" spaceflight work as soon as possible. The module functions as a capstone to the minor program and allows the student to conduct work very similar to work actually done by professionals. This overall goal is reflected in the learning objectives, which are twofold: first, students conduct a "deep dive" into a specific spaceflight topic, demonstrating that they are able to immerse themselves in a space problem, conduct appropriate work and deliver a work product which is focused within one of the spaceflight topic areas covered by the minor. Second, students demonstrate that they can work in the complex spaceflight context by critiquing the work of others, and by defending their own work, based on their background and the knowledge gained during the minor. This second objective forces the student to think outside the box of their own topic specialism, which is an important ability in the multidisciplinary spaceflight environment.

Each student works individually, or in a small group of students, on producing a clearly defined work deliverable. The deliverable closely resembles a work product that a professional in the field would produce, adapted to be achievable within the constraints of the minor. The work product deliverable is sharply defined as a Spaceflight Assignment by a tutor who is a specialist on the topic. The tutor designs the assignment, supervises the student during the execution of the work, and takes a leading role in the assessment of the results. Assignments are focused on a narrow, well-constrained topic with a clearly described deliverable; this approach is intended to eliminate purely conceptual, paper-only assignments and to minimize the amount of group work and similar "overhead", which is amply developed in other courses in the curriculum at TU Delft, thus allowing the student to focus on the "deep dive".

Assessment is based on three components. The first component (70%) is based on the work product delivered and an accompanying report of about ten pages covering the results, analysis and conclusions related to producing the deliverable. The second component (15%) is based on a written, technical critique which the student must provide as feedback to a fellow student who is working in a different topic area; the critique may include incisive or exploratory questions as well as tips for improvement, for example. The third component (15%) is based on a written defense of the work produced; this defense may be a direct response to the critique received from fellow students or from the tutor. Assessment is supported by a rubric, which is a matrix of assessment criteria versus criteria score and which guides the assessor to provide consistent and uniform scoring across the student population.

The topics for the assignments reflected the diversity of subjects covered in the minor. Some focussed on hardware such as building a Sun sensor or water rocket and evaluating its performance. Others dealt with the study of the effects of space environment phenomena such as radiation on spacecraft, the analysis of planetary observation data for Saturn, Venus and the Galilean moons, the algorithmic detection of craters for landing vehicles, the determination of satellite orbits or the optimization of GNSS satellite parameters.

5. Results and feedback

The first run of the spaceflight minor in 2015-2016 can be considered a success. The collaborative, multidisciplinary nature of work in the spaceflight arena was reflected well in the enrolled student group, the contributing lecturers, and the topics covered. In the first year of enrollment, the background of the students was well distributed over the engineering faculties at TU Delft (see Fig. 2), with fairly even distribution over the faculties of Mechanical, Maritime & Materials Engineering (32%), Electrical Engineering, Mathematics and Computer Science (27%), and Aerospace Engineering (25%). The faculty of Applied Sciences was also well represented (14%), and students from Civil Engineering & Geosciences also participated (2%).

In addition to drawing students from a number of non-aerospace faculties, the spaceflight minor remains attractive to BSc students of Aerospace Engineering; this is influenced by the fact that the BSc program contains relatively few space-related topics and that the minor was designed to contain minimal overlap with both the BSc and MSc programs of the Faculty of Aerospace Engineering.

The participating lecturers not only contributed to the wide variety of topics covered in the modules, but collaborated to support the cohesion of the minor program as a whole. Prerequisite knowledge for later modules was introduced early on where possible, assessment was balanced to ensure a variety of evaluation methods were employed, and topics included in the modules covered a wide spectrum of spaceflight activities: from hardware to algorithms and data, from spacecraft engineering to planetary science, astrodynamics and astronomy.

The success of the minor is reflected in a student survey to which 60% of the participating students responded. Survey respondents generally felt that their level of knowledge on spaceflight was deepened (100% of the respondent agreed) and that the course modules were well-aligned with each other (77% agreed). In terms of student motivation, 96% of the respondents agreed they enjoyed the minor and 98% agreed that the minor boosted their motivation to study in general. In terms of their attitude towards spaceflight, 69% agreed that they were considering pursuing an MSc in spaceflight. In general, respondents felt that the overall quality of the minor was good (92% agreed), and 97% would recommend this minor to other students.

The spaceflight minor was run for the first time, and this resulted in a number of issues which can be improved upon: for one, it was not always possible to generate sufficient exercise material that was tailored to the unique context of each topic within the minor; secondly, the actual study load was, for a few modules, not properly in line with the expected study load of 28 total study hours per ECTS. And thirdly, the expected level of student knowledge upon entry to a module was sometimes in excess of the actual knowledge.

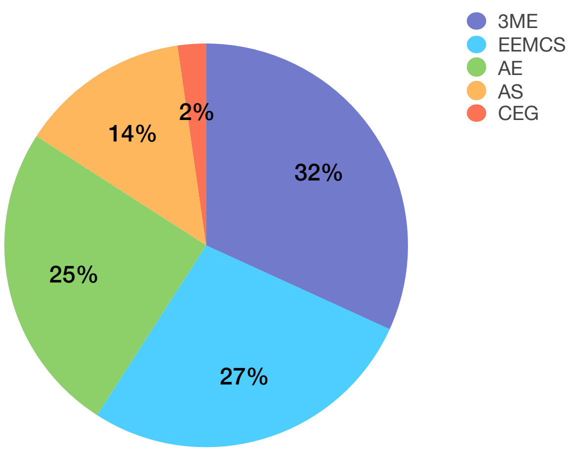

Fig. 2 Student enrollment by faculty

6. Final words

All in all, the spaceflight minor can be comfortably deemed a success. Student expectations were broadly met and frequently exceeded. Lecturers enjoyed participating, a factor not to be overlooked, and were able to align their areas of expertise with the topics that were treated. Furthermore, it was demonstrated that valuable education can be delivered in a challenging, multidisciplinary setting, and that a diversity of educational methods and delivery formats can, if thoughtfully designed and executed, enhance the quality of an extensive program such as the spaceflight minor.

The second edition of the spaceflight minor runs from September 2016 to January 2017, and 50 students are enrolled as of 8 September 2016. The online course variants for Introduction to Spaceflight and Spacecraft Technology are also running in this, their second academic year.

References

[1] Delft Space Institute, *http://spaceinstitute.tudelft.nl*
[2] European Credit Transfer and Accumulation System, *http://ec.europa.eu/education/ects/ects_en.htm*
[3] European Space Agency, *http://esa.int*
[4] Indian Space Research Organization, *http://isro.gov.in*
[5] National Aeronautics and Space Administration, *http://nasa.gov*
[6] *http://rosetta.esa.int*
[7] *https://www.nasa.gov/exploration/systems/sls/*
[8] *http://www.isro.gov.in/pslv-c25-mars-orbiter-mission*
[9] *http://www.nasa.gov/kepler*
[10] *http://spacex.com*
[11] *http://www.delfispace.nl*
[12] TU Delft's online learning platform, *https://online-learning.tudelft.nl*
[13] *http://turnitin.com*