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Using the Engineering Design Cycle to Develop Integrated Project Based Learning in Aerospace Engineering

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Abstract: *Over the past four years the Faculty of Aerospace Engineering at Delft University of Technology in the Netherlands has redeveloped its BSc curriculum to mimic an engineering design cycle. Each semester represents a step in the design cycle: exploration; system design; sub-system design; test, analysis & simulation; verification & validation.*

In the curriculum design each semester has an accompanying project allowing students to synthesize their learning. These projects are done in groups of 8-10 students to accommodate our annual intake 400+ students. All projects share a common set up in terms of having a storyline, professional roles for students, having a client for each project and being real-life and authentic. The first project has students discover the possibilities of using UAVs to explore solar systems. The second project allows students to design & manufacture an aerospace structure loaded under bending & torsion. The third project has students design a sub system of an aircraft or spacecraft and in the fourth project students analyse actual scientific test data with a view to write a (mock) scientific article. Finally, in the third year the curriculum is capped by a Design/Synthesis Exercise in which students have to complete an entire design of an aerospace related object. Integrated in the first two year are courses on technical and scientific writing as well as oral communication.

This paper will report on each of the projects, their set up, the experiences of running the project and student evaluations after running a complete three year curriculum also highlighting the challenges of working with such large numbers.

Introduction

In 2007 the Faculty of Aerospace Engineering at Delft University of Technology (TUDelft) started a major revision of their bachelor curriculum. Over the years the curriculum had undergone many changes due to a variety of government and European measures as well as developments in the field of aerospace resulting in a chequered curriculum with little structure. At the same time the number of students after heavy fluctuations in the nineties had steadily grown well exceeding 450 per year. This also brought with it many extra challenges.

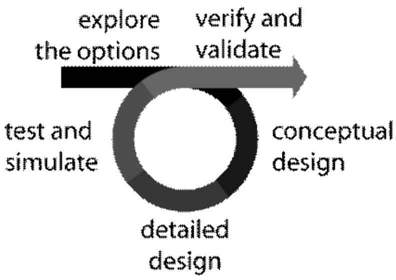

Figure 1: Engineering Design Cycle (Kamp, 2011)

The result was an all new curriculum based on the design cycle of an aerospace vehicle (see figure 1). The bachelor curriculum consists of 6 semesters, 5 of which are themed according to the design cycle: exploration; conceptual design, detailed design; test & simulate; validation & verification and a minor of 1 semester scheduled in the first period of the third year in which students are encouraged to take an interest in another field of engineering or related studies.

All courses were streamed into each of these themes. Next to creating a strongly themed curriculum thus providing students with strong learning lines and storylines also the way the curriculum was taught was addressed. All lecturers were encouraged to make use of active learning methods such as in-class labs, studio classroom sessions, clickers etc. Several courses replaced their traditional exam with other assessment methods. For more detailed information on this curriculum and its development the reader is referred to Kamp (2011) and Faculty of Aerospace Engineering (2012).

Although there was already a strong presence of project based learning (De Kat & Saunders-Smits, 2009, Brügemann et al., 2005, Saunders-Smits & de Graaff, 2003) at the Faculty of Aerospace Engineering at TUDelft, it was decided to make their presence more central to the theme. Therefore each thematic semester was given its own themed project. This paper discusses the teaching philosophy used behind the design of the projects, each of the actual projects and the outcomes so far and finishes with a reflection on the lessons learned after three years of implementation.

Project Education Philosophy at Aerospace Engineering, TUDelft

When developing the projects it was set out in the curriculum development phase that the projects should meet a number of requirements. It was felt that it was important that students learn to work in teams and also that students were gradually given more responsibility. It was also felt that it was important to hold students individually accountable and that measures to avoid plagiarisms and free loading must be taken as well as measures to introduce more individual assessment. Next to that it was felt that students should be encouraged to develop their self reflection and feedback skills to better prepare them for the future as well as developing their oral and written communication skills. As a final requirement the project should allow students to put into practice the material they studied both in the preceding and in the current semester(s).

In order to achieve this, a total of 5 projects were (re)designed. In designing these projects extensive use was made of the framework as presented in de Graaff & Kolmos (2007). They show that in order for project education to work there should be a hierarchy of more independence for students as they mature through their degree. Therefore the projects in the first year can be classed Task projects, the projects in the second year as discipline projects and the Design/Synthesis project in the final year of the BSc as a Problem project.

Project Set up Commonality

Even though student independence is growing in each project much attention was paid to a common set up of each project. Each project would have its own storyline, and each project would have to ensure that its design topics were authentic and resemble real life engineering practice ensuring that students would have a compelling experience in a contextual environment (Inman, 2000 and Kamp, 2012) and are intrinsically motivated (Lepper & Hodell, 1989 and Malone & Lepper, 1987). Each student will have a clear engineering role and each project will have a client and resemble true engineering processes as much as possible. Also each project would aim to teach students one or more engineering skills.

Manpower

With several hundreds of students to accommodate in projects every year, the manpower required for running these types of projects is high. To alleviate pressure on staff, extensive use is made of teaching-assistants, third year BSc and MSc students, in the first three projects discussed in this paper. Using senior students as teaching assistants is a very effective way of tutoring groups with benefits for all parties involved provided they are properly trained and supervised (Andernach and Saunders-Smits, 2006 and Saunders-Smits and van den Bogaard, 2009). The remainder two projects are manned by PhD students and staff. Doing it this way makes it possible to successfully run projects for large numbers of students coordinated by only a few members of staff.

As an example, in the first project in the second year (AE2100) one teaching assistant (TA) is assigned to every two groups. The latest version of the project counted 23 TA's. They have the task to offer an adequate amount of supervision, guidance and assistance and they are heavily involved in the grading process. Teaching assistants in this project are first year (MSc) students with sufficient background in the design area. Weekly lunch meetings are scheduled with the project coordinator to check compatibility with the project (learning-) requirements and to exchange information. In some cases other staff members join to answer particular TA questions about the work package contents. Prior to the start of the project the TA's follow a one day training dealing with the specifics of team coaching such as observing, listening and motivating (figure 2).

Figure 2: Picture taken during training of teaching assistants. The TA's are challenged to pick up the relevant information from a story read by a colleague.

Peer and Self Evaluations

To stop freeloading active use is made throughout all projects of the principal of Peer- en Self evaluation. The advantages of their use are well documented in Topping (1998). All students are required to perform a peer and self-evaluation twice per project. The results of this evaluation will serve as input for the tutors in the coaching and grading process. To this a computer based system for peer and self evaluation was developed (van den Bogaard and Saunders-Smits, 2007). This system was so successful that it has now been adopted university wide and its development has been taken over by a commercial company, Parantion as part of their personal feedback software Scorion. To help students structure their feedback they are asked to score their peers and themselves in a rubric format developed at the US Air Force Academy using the criteria: job performance, technical quality, attitude, initiative, management of resources and communications. Students are also asked to motivate their choices.

Project AE1100 – Exploring Aerospace Engineering Project

Introduction

The AE1100 project is a first exploration of the aerospace engineering field, which means it aims to enhance knowledge taught in parallel courses by using the exploration theme. The project is focused on flying wings, which have long been a dream of a number of designers. The students are therefore tasked with the design, build and flying of a small flying wing made out of Styrofoam controlled by two small electrical engines. Their professional role in this project is that of Feasibility Leader.

During the project students will explore the first elements of aerospace engineering. The biggest problem found of course when building a flying wing aircraft is that such designs are inherently unstable and they do not easily stay level in flight. Yet such an all-wing aircraft would have excellent payload and range capabilities because it produces less drag than a conventional aircraft as the tail and the fuselage of a conventional aircraft are responsible for a significant amount of drag. Eliminate the tail and fuselage and you might be able to eliminate a great deal of drag, enhance performance, reduce the amount of fuel required and improved the handling capabilities of the airplane; an attractive prospect in the age of fuel running short and an increase in air traffic transportation.

Learning Objectives

At the end of the AE1100 project students must be able to:

- explore the reasons behind the design of an aerospace vehicle
- apply the knowledge from the related courses
- find relevant scientific information and reference them in an academically responsible way
- work in small groups and reflect on your role within the group

Set up

The project consist of 14 half days of work in the course of seven weeks, including several experiments in the different laboratories.

To get acquainted with pressure distribution on airfoils, vertical tunnels are used to explore the flow and pressure distribution around a wing profile at different angles of attack. Exercises help students to become familiar with Bernoulli's law and mass conservation.

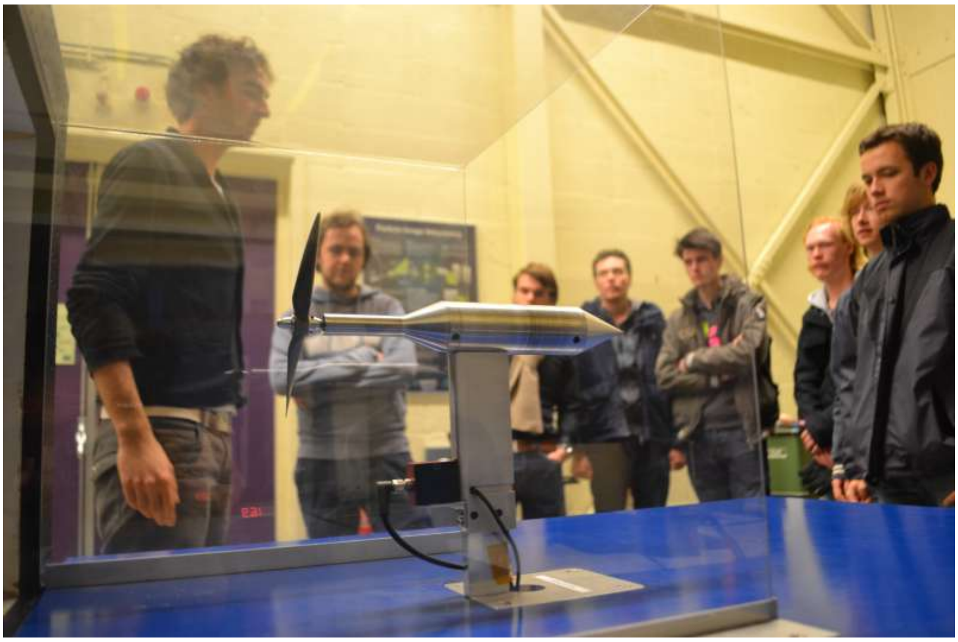

Figure 3: Students using propeller set-up

To learn about how much thrust their flying wing can produce; students use a propeller set-up in a wind tunnel to measure the effects of blade pitch, rotational speed and forward velocity on the thrust of a propeller blade (figure 3). Students also use blade element theory in Excel to correlate with their measurements.

An open jet wind tunnel in which a 3D model of a swept flying wing is placed is used to illustrate and measure 3D effects on finite wings with sweep. From close up they can see how the forces and moments are affected by velocity and angle of attack. Vortexes, boundary layers and stall are also demonstrated.

As they are learning about a solar powered flying wing students measure how the productivity of solar cells, which could be used for a solar powered flying wing, depends on distance and angle using different type of LED's.

The main group deliverable of the project is a poster, on which they explain the flying wing mission they design. Next to the poster, the students also have to design a scale model, which is cut from EPP foam. At the end of the project they add electronics and engine to this wing, after which they fly it in a large hall as the closing of the project.

Assessment

The final grade of the project consists of three parts: The first 40% is based on individual behaviour and is based on an evaluation by the tutor. To aid the tutor in this evaluation and monitor the group process, a peer evaluation is held halfway and at the end of the project. Another 40% is based on the gained knowledge and is the outcome of an individual multiple choice computer test at the end of the project. The final 20% of the grade is an evaluation of the poster by a jury of multiple lecturers of the university, using grading rubrics. Especially the test is an element students can actually fail the project on, though a few students have also failed on the basis of their evaluation.

Experiences & Reflection

An evaluation in the first year showed that 99% of the students thought that the course fit well with the theme of the first semester (Exploration), 88% indicated that there was enough cohesion with other courses and 82% agreed that the project motivated them in their study.

On the downside, 36% of students thought that the link between parts of the project was not strong enough, especially the parts related to team working skills and information literacy training, even though most students indicated that they thought they needed the knowledge from these parts after the project. These parts have since been taken out of the project and placed elsewhere in the curriculum as they were indeed not required for the theme of the project and appeared to confuse students.

Project AE1200 – Design & Construction Project

Introduction

The second project, the AE1200 project ‘design and construction’ is highly object oriented. It focuses on the design of a thin walled stiffened structure loaded under bending and torsion: the structural part of an aircraft wing box. This project is setup around the design cycle where the students first design their wing box, then produce it, place measurements instruments on the box, test the box and analyze the measured data. After this preliminary design cycle, the students get the opportunity to put their lesson learned to the test by redesigning a substructure of the wing box. Incorporated in the project is a technical writing course allowing students to gain much needed technical writing skills. The professional role of the student in this project is that of the Structural Engineer.

Learning Objectives

At the end of the project the students have to show that they are able to:

- Independently complete a full design cycle of an AE (sub)system
- Manage a complex team project under strong external guidance and reflect on its outcome
- Write an effective design report

Set up

The project consists of a total of 37 project sessions, running for a total of 14 weeks. Students will have project on average 2-3 times a week. A majority of these sessions is done at project tables where students do the theoretical work. Throughout the project there are four production sessions where the students produce their designs and three test sessions. Students work in project teams of 8-10 students and are supervised and guided by teaching assistants. Each teaching assistant supervises two of project groups.

During the project the students have to prepare a total of 7 deliverables (for example: a literature study report, a design report, a design review presentation and a final report). Most of the intermediate deliverables are used in a formative way: to accommodate the learning process and are therefore not directly graded. These deliverables are discussed in 5 feedback sessions.

The project starts with a literature study, where the students get familiar with the topic. In the third week of the project, students can start their design. Their task is to design a wing box structure of 1500mm long with a cross sectional area of 400x150mm that has to withstand a buckling load of 2500N and a failure load of 5000N. For this design, the students are allowed to use only one type of material (aluminium) of a set thickness. This is done in order to reduce the number of design parameters and therefore reduce the complexity of the design. The students then produce the wing box and make an instrumentation plan in which they place strain gauges onto the wing box. After instrumentation, the design is put to the test. This is a very interesting moment during the project as the students see the results of their calculations (figure 4). The first part of the project is finished by analyzing the test data and making a test report and design presentation.

Figure 4: The wing box in its test rig with buckling clearly visible on the top panel

After the design presentation, the redesign phase starts. Students will design, produce, test and analyze two specimens. These specimens are a substructure compared to the wing box, as only compression specimens located on the top of the wing box are to be designed. At the same time the level of difficulty of this design is increased as more design freedom is given and the students need to experiment more with what formulas are most suitable for this design. This design is then also tested as can been seen in figure 5.

Figure 5: the redesigned top panel in its test rig

At the end of the project, the students have to come up with a final design incorporating all the lessons learned during the project. This design is presented in the final report of the students. At the end of the project, the students have to take a computer test in order to show that the learning goals of the project are met.

Assessment

The assessment of the groups is done both in group performance as well as in individual performance. There are grading sheets that are used for all aspects of the grading process. The final grade consists of the five parts. The first two parts are a group grade the final three parts are individual grades.

- Oral presentation on the design and the test results given by the group (10%), mid way through the project. The students have to present their work to their tutor and a member of staff.
- The final report (20%) in which the technical content of the report is assessed
- Grade for their individual technical writing skills (20%). The set up of the final report is assessed and each student has to write a report cover letter to show they have gained basic technical writing skills.
- An individual electronic test (30%). In this test the understanding of the subject matter of each individual student is assessed in order to ensure that each student meets the learning goals
- The individual contribution to the group (20%). For this the individual contribution to the group process is assessed using rubrics. This way, students that were not actively involved during the project will not pass.

The most common way to fail the project is by either failing the electronic test or failing to meet the quality of the final report. However, fails on one of the other components also occur.

Experiences & Reflection

The standard student evaluation in the first year of running (2009-2010) showed that 97% of the students thought that the course fit well with the theme of the second semester ("design and construction"), 88% of the students indicated that there was enough cohesion with other courses and 63% of the students agreed that the project motivated them in their study. Also 65% of the students have indicated that the project formed a coherent course. In addition to this 94% of the students have indicated that the technical writing course is useful for them and 81% indicate that this course is well integrated into the project.

Remarks regarding possible improvement of the course indicated that students found writing reports with 10 students very hard to do and that the space part of the assignment was not integrated well enough in the project. It has proven very difficult to combine a typical aircraft topic (as a wing box structure) with a topic related to space structures. This is a topic of continuous improvement for this project and will be worked upon over the next few years.

Project AE2100 – System Design Project

Introduction

The first year projects aim at giving the students experience and practical examples in the field of aerodynamics and structures. In the first project in the second year both are combined into a design project in which they have to integrate the knowledge to come to a good design. The students are given a certain amount of autonomy to come to a group performance. The professional role the students have is that of the Lead Engineer in an aircraft or spacecraft design office in which they design an aircraft wing or a spacecraft on a certain mission/

Learning Objectives

The project has a number of goals:

- First, it aims at providing learning experience for students enabling them to better integrate the (theoretical) content of thematic courses in a practical, active setting. Students learn to determine and describe design options, evaluate the performance of (sub-)systems and describe trade-offs and reflect on the selected design.
- Secondly, it aims to stimulate the working in a team, which means that besides the performance of the technical assignment, also the work organization, consultation, coordination, and communication and tuning between members are considered as important contributions to a successful project.
- Thirdly to teach students how to prepare an oral presentation on a technical subject in an efficient manner using effective visual aids.

Set up

Project technical content

The students work in teams of 8 during the first second year semester. They spend two blocks of 4 hours per week on the subject. Their assignment is to design a wing for one of 4 different jet aircraft or to design a spacecraft for one of 4 available missions. The aircraft type ranges from a long range business jet to a long range passenger jet. The space assignment deals with craft ranging from a low-earth orbit satellite to study the lower thermosphere and re-entry to an unmanned probe to Mars.

The aircraft and space missions are characterized by a number of high level requirements, such as payload, cruise Mach number, take-off and landing distances and range for the aircraft and mission duration, payload mass and power and launcher related issues for the spacecraft. The assignments are randomly distributed over the teams.

The project is organized around 5 work packages, each with their own deadline. If the wing project is taken as an example, the first period of 7 weeks is dedicated to the aerodynamic design of the wing and the associated subsystems such as high lift devices and control surfaces. The three work packages cover aircraft initial sizing, wing plan form design and wing sub-systems design.

The second part of 6 weeks deals with the loads on and the structural design of the wing. Work will vary from wing box design to detailed structural design of control system fixture, focusing on e.g. flange sizes, connections and structural interfaces.

Project communication content

Next to the work on the technical part the students follow an oral presentations course. At the start of the second period each group has to present the mid-term result of their project work. This mid-term presentation involves every individual member of the group and it is the first presentation they do on the subject. The presentations are recorded and serve as the basis to further enhance the student's personal presentation skills in the next 4 classes. At the end of the project the final presentation, covering the group's project achievements, will reveal the progression each individual student has made on this matter.

Coaching

Assessment

The students are assessed on 4 different project components. Consequently their final individual mark consists of 4 grades:

- An Individual grade for job performance and academic and project skills (20%)
- A group grade for the reports on each of the work packages (40%)
- An individual mark for the oral presentation course, given by the course lecturers (20%)
- An individual mark for the project essay (20%)

The TA's grade the group work package reports using detailed scoring sheets containing e.g. the report's completeness, it being in line with requirements and its readability as well as the quality of the design work carried out, presented in the document. As previously told all projects include the use of Peer and Self evaluations that are carried out twice, one halfway the project and one at the end. Together with their personal observations the TA's will use these reviews as input to come to a personal grade using a set of rubrics. The essay has to be written at the very end of the project. It is a hand written document produced by the student in a plenary session to show his knowledge of the design process by answering questions about specific elements of the design. The basic question to answer is: "what if…". As an example students are asked to write down what happens to the design of the wing if the requirements were changed to fly the aircraft at a higher cruise Mach number or what happens if the number of passengers would double.

Experiences & Reflection

The project has run twice until to now, the first year without a space component. Students are very positive about the possibility to bring into practice what they have been learning in the first year. The students appreciate (some 60%) the coherence with the first year courses such as Introduction to Aerospace Engineering, which contains aerodynamics, materials and flight mechanics and Aerospace Design and Systems Engineering Elements. From the standard student evaluations carried out in the winter of 2011/2012, 74% of the students indicated that they found the project useful, 85% felt actively involved, 70% found the project sufficiently challenging and 41% found the project motivating.

In the beginning staff observed that students seemed to have difficulty in planning to meet the deadlines of the work package reports, but this becomes increasingly better in the course of the project. A point of attention is the fact that the second period containing the construction work packages are experienced as more difficult that the first period with the aerodynamic layout of the wing. The oral presentation course was found to be very valuable (by 90% of the students) for their personal development.

Project AE2200 – Test, Analysis & Validation

Introduction

As previously reported in Saunders-Smits (2011) this project was designed with the aim in mind for students to work with real data form real research projects ongoing at aerospace engineering. The students have the role of Data Analyst and/or Test engineer. The choice for using real data rather than fabricated data was made to ensure that student motivation remained high. It was decided that given the sheer number of students in the project (over 350 per year) it would not be possible for students to generate all the data themselves for practical, logistical, time and financial constraints.

Learning Objectives

The project aims for students to reach the following objectives: at the end of the project a student should be able:

- To analyse an experimental set-up or simulation model and assess its performance with regards to answering the posed research question;
- To carry out an analysis of experimental and/or model results;
- To draw conclusions with the aim to answer a research question;
- To write a research report and present the research to others;
- To function as a member of a research team in a research environment;
- To be able to critically reflect on one's own research as well as others using a peer format.

Set up

For this project students are randomly divided in groups of 8. Each group is then assigned a staff member who has written a research assignment. This staff member is typically a junior staff member such as a PhD student, a post doc or an assistant professor.

Each project has a standard set up of activities. Each group must carry out a literature study to understand the background of their given research question, which is then followed by the actual data analysis. The results of the data analysis then need to be verified through comparison with theory, simulations, and literature and subsequently interpreted, resulting in conclusions with regards to the research question and recommendations. The second step in the project is then documentation. The research question, test, simulation and analysis results, and the conclusions must all be written up in a comprehensive six-page scientific report mimicking a journal article.

In the project ample attention is paid to academic skill development. The focus in this project is on Information Literacy, Self reflection skills and Scientific Writing. Information literacy is dealt with by means of a computer-based online library course designed by the TU Delft library allowing students to become acquainted with searches in academic resources such a Web of Science and Scopus as well as with the need to cite appropriately and plagiarism. To help students develop a scientific writing style, they are offered six two hour classes in scientific writing. This is done by the team from the Institute of Technology and Communication an in-house institute within Delft University of Technology that offers courses for students in languages and communication. All deliverables for these assisting courses are incorporated in the project.

To develop their (self) reflection skills students are expected to write a self-reflection both during and again at the end of the project. The students should reflect both on their technical input as well as how the functioned within their research group. In another form of reflection students have to carry out an individual peer review of the scientific report produced by students from other groups. This has as an added bonus that each group receives 8 reviews of their paper!

The project has been designed in such a way that students are given an idea of the ways of working in the world of research. The project is closely linked with other 2nd year courses such as Probability and Statistics, Experimental Research and Data Analysis, Applied Numerical Analysis and Computational Modelling allowing students to also see the synthesis between courses as is intended in the overall curriculum design. In order to follow on from the first year programming course Matlab^{TM} was used as the official programming language during the project.

The topics of the assignments spans over the entire aerospace research field as represented with the Faculty of Aerospace Engineering. Some examples are:

- The effect of motion cues on manual aircraft control
- Hearing thrust from flyover sound
- Force-Time history Analysis of impact on (AP-PLY) composite laminates
- Landing site characterization and analysis of a mission to Mars
- Re-entry of a CHAMP satellite
- Analysing the flow field around a wing in transonic conditions

Assessment

The students receive an individual grade for the project. This grade is based on a collection of individual items and group deliverables. They consist of a 6- page scientific report written by the group, the attitude of the student during the project, a written individual self-reflection in which students are asked to reflect on their own contribution to the project, an individual oral exam at the end of the project and an individually written peer review of another group's scientific paper.

For each of these items extensive use is made of scoring rubrics to ensure uniform grading across the many different members of staff involved as well as to ease the grading work load as a whole.

Experiences & Reflection

The project ran for the first time in the spring of 2011 and is now in its second run. Overall the experiences are positive. From a staff point-of-view, they were positively surprised by the commitment and the level of ability of the students. They reported it was very inspiring to work with the students. As a points of development they indicated that tuning the assignment to the right work load was something that they as staff needed to work on as well as their ability to motivate students to not cut corners but take all the steps in the research (such as not skipping the literature study). Another issue was the large variety in programming ability. From the standard student evaluations carried out in the summer of 2011, 72% of the students indicated that they found the project useful, 80% felt actively involved, 73% found the project sufficiently challenging and 53% found the project motivating. From an organising point-of-view lessons were learned with regard to reviewing the assignments prior to starting the project as to their suitability and feasibility. A second point of development is the ability of students to reflect on their own work and their ability to write constructive reviews. The scientific writing course is being adapted to assist students with these matters. A point of concern however, remains the high number of students in the course and the work load this represents for the staff.

Overall the project is a great success and ample proof that students can be interested in and able to carry out research problems as much as engineering problems. To illustrate this success this year's papers will be published in small book.

Project AE3200 – Design/Synthesis Exercise

The Design/Synthesis Exercise is the capstone project of the BSc curriculum in aerospace engineering. It also serves as the Bachelor thesis for all the students. In contrary to the other projects, this project is a full time activity for the students. It runs over the second half of the second semester of the third year (April- June). For students lagging behind every year there is a second opportunity to take part in the exercise. This second exercise runs in the second half of the first semester (November – January). The students are expected here to show their overall competence in engineering design. Their professional role in this project is that of the Systems Engineer.

Learning Objectives

The learning objectives for this exercise are that at the end of the exercise the student must be able to:

- Design a multi-disciplinary (sub) system or inventive arrangement of system elements using techniques from systems engineering and taking into account societal, environmental & ethical considerations. This system can either be hardware focussed (e.g. aircraft or spacecraft) or operations focussed (e.g. airport or space mission). However, every assignment should contain a serious hardware design part.

- Autonomously acquire additional knowledge required for obtaining the solution to the design problem posed.
- Communicate their design and its process to their peers, the aerospace engineering academic staff and informed third parties
- Function as a member of a team and be able to reflect on their performance in such a team

Set up

The DSE is a ten week, full time activity for groups of ten students. It takes half a semester to complete. The study load is 15 credits in the European Credit Transfer System (ECTS) which equates to a work load for the student of 400 hrs. Translating this to a working environment it means that a group of students in the exercise carry our a combined equivalent work load of 2.5 FTE.

Students work together in groups of ten, in large project rooms, each hosting 4 – 8 design teams. Each student design team is supported throughout this project by a principal tutor and two coaches from the aerospace engineering faculty, each with different aerospace fields of specialism to ensure the multi-disciplinarity of the design. Teaching assistants are not used within this project for educational tasks. There is a limited number of teaching assistants (2-3) involved but only for administrative support.

The principal tutor is responsible for the design assignment. All design groups have different design assignments to work on. This makes the designs challenging for the students and the tutors as well. There is no such thing as a standard assignment. Every year new assignments are brought forward by the principal tutors.

Example of design projects are the design of Micro Unmanned Vehicles, missions to Mars, formation flying satellites but also more outlandish designs such as a solar car, an electric buggy for the Dakar race and underwater robots. Quite a few of the projects continued after the exercise and were built and operated by students in their spare time.

During the exercise, the whole process of designing is addressed, from the list of requirements up to the presentation of the design. Typical aspects of real design processes, such as decision making, optimization and coping with conflicting requirements are therefore encountered on a regular basis throughout the whole exercise. Acquiring experience often means going through iterative processes, so design decisions must be continuously reviewed to make sure that the design requirements are met. The duration of the exercise is limited. Therefore, also the number of iterations will be limited. However the students do experience the true iterative nature of designing.

During the exercise, the educational staff reviews the students' decision processes and overall management of the project. Aspects of design methodology and design management are also reviewed. The educational staff also provides technical assistance for aspects of the projects where the students lack sufficient background. This means that the staff is playing several roles throughout the project. One time they are the client, another time they are the expert in the field and yet another time they are the teacher that grades the student. The students have to distinguish between these roles which may be confusing in the beginning.

Assessment

The assessment of the design work of the students and the design process is done throughout the whole duration of the exercise. Each student will receive an individual grade for the exercise. This grade is given by the principal tutor and their coaches. The grade consists of a group component (40%) reflecting on the quality of the design and the process and communication of the group as a whole as well as individual component (60%) relating to the individual's understanding of the design, the methods used and the quality of their individual contribution as well as their effort, communication skills and team working skills.

The team of coaches will meet with the students in both a scheduled and a non-scheduled way. At least once per week there are planned progress meetings. Furthermore there are three formal reviews throughout the exercise (base line review, midterm review and final review). On the basis of these meetings and reviews the coaches are required to formally assess and grade the students twice throughout the exercise. The first grade, handed out after the midterm review, only serves as feedback to the students, the second grade is given at the end of the exercise and is the final grade. To grade this effectively a comprehensive set of rubrics have been developed allowing for uniform standards over the plethora of assignment topics. For more information on the rubrics the authors refer to Saunders-Smits and Melkert (2011).

Experiences & Reflection

This exercise now runs for over 10 years. In its early beginnings it was largely based on previous aircraft preliminary design exercises taught at the faculty. Those design exercises were very limited in their scope. They only included standardized aircraft designs and there was a standard set of requirements. Next to that, those assignments were only done by a fraction of the students. Nowadays the exercise is compulsory for every BSc student and the assignments are different every year. Next to that the scope is significantly widened in the sense that spacecraft and mission designs are also included. Another thing that has changed was the group size. This went from 4 students in the past to 10 students per group today. The consequence of this is that the designs can be much further elaborated upon and become more mature. Furthermore, the team process became more important. On the other hand the increase in group size also resulted in more team management related activities and thus less design activities per student. This in itself is not a bad thing. In their future career students often will have to work in large (multinational) teams that require serious management efforts as well.

The design assignment offered is time consuming, both for the staff and the students. However, the amount of complaints received on workloads being too high is very limited. The students know upfront from their fellow students what is expected of them and they want to live up to the expectations.

In order to reduce the workload for the staff the option to redo a design assignment of a previous year has been offered. However, this option is hardly being used. Tutors are really keen on coming up with new assignments every year. On the other hand there are some signals from the quality control committee that reviews every assignment that the originality of new assignments is decreasing. This is something that must be monitored closely in the future.

Overall student satisfaction is high. An often heard quote from students is that it was the best thing they did in their degree so far. From the standard student evaluations carried out in the summer of 2011, the students scored the exercise as a whole as 8 out of 10, and more importantly 68% of the students said that they have a better understanding of the relationships between the different disciplines in aerospace engineering, 85% felt that the exercise contributed to a better understanding of design and 91% indicated that the exercise contributed a lot to their competence in working in teams.

Conclusions & Recommendations

As the contents of this paper illustrates, it is possible to run large scale design project for students in a meaningful way. It takes a lot of skill in organising but can be managed well by a small number of academic staff supported by a large team of teaching assistants and/or post graduate students. It also shows it is a very worthwhile undertaking: students highly appreciate this type of education next to their traditional class room session as it uniquely allows them to practice engineering in (controlled) environments mimicking real life engineering practice.

The authors would argue though that a good organisational structure and tuning of the projects to the accompanying courses and local facilities is important for their success. If those conditions are right, your students will blow you away with their enthusiasm, dedication and most importantly their level of skill. The authors also would like to emphasis the importance of training of staff members who supervise projects. Training will pay off in the quality of tutoring and therefore greatly improve the student’s experience and more importantly their opportunities to learn to be engineers.

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