THE EFFECTS OF THE INTRODUCTION OF A PROJECT-BASED CURRICULUM IN THE MECHANICAL ENGINEERING COURSE AT THE UNIVERSITY OF TWENTE

Theme: Project organisation

E. M. A. Peters and P. C. Powell
Educational Centre / Faculty of Mechanical Engineering
University of Twente
The Netherlands

Abstract
The Faculty of Mechanical Engineering started with project-based education in 1994. The reason for this transformation of the curriculum was the decrease in student progression and the insufficient mastery of essential skills such as problem-solving and communication. Projects are now a substantial part of the program. In addition, courses are block-structured. In general, the results with the new curriculum are positive: students are more motivated and student progression has improved. Staff members are enthusiastic about the projects and their results, and the new program has a positive influence on cooperation between specialist groups in the faculty. However, we are aware of some problems that are not solved yet, for example the difficulty of assessing individual students in the projects.

As a prelude to our paper, we would like to give you some anecdotal account of the difference between two engineers with different educational backgrounds (the story is based on a conversation with an engineer from a Danish firm handling steel construction work).

The story of the two engineers

A firm gave two engineers a project to find a solution for a particular problem. One was a Danish engineer who had followed a project-based education, the other a German engineer who had followed a classical programme. Both engineers were given a fixed time within which to reach a solution. At a certain moment both gave a presentation of the solution they had developed.
The German engineer was thoroughly prepared, had worked out everything in fine detail and came with a good well-balanced down-to-earth proposal. The solution from the Danish engineer was more global, less worked out in detail. He showed a good understanding of the problem.
The firm was not completely satisfied with either proposal; they had thought in another direction and really wanted another sort of solution. The Dane reacted on the spot and had several other alternatives which he could explore at once. He clearly indicated a flexibility in his thinking process, could think with the company and came up with creative solutions.
In contrast, the German said that he had not prepared this change of plan, and preferred to come back a week later with a new fully-worked-out proposal.

This difference in reaction to an unexpected situation indicates one difference between the two differently educated engineers. Which engineer would the firm prefer?

1. Introduction

In 1994 the curriculum of the Faculty of Mechanical Engineering at the University of Twente in the Netherlands underwent a significant change, inspired by the educational philosophy of the University of Aalborg in Denmark. The innovation consisted of the introduction of project-based education and the transformation of the traditional trimester structure to a block-organised structure. It is the purpose of this paper and the presentation to offer more information about the curriculum innovation in general and the projects in particular. We will focus on the results of the new program; both the positive results and goals that are not reached yet will be mentioned.

Firstly, we will give you some background information about the University of Twente and the Faculty of Mechanical Engineering. The university is relatively young (founded in 1966) and small, with a total of 6500 students divided over thirteen different courses. It is a so-called 'technical university', which means that most students are educated to become an engineer (Master of Science) in, for example, Computational Science, Chemical Engineering, Mechanical Engineering, or Electrical Engineering. However, there are also three courses that belong to the social sciences. But in these courses the engineering approach is also present, meaning that learning to design solutions to concrete and practical problems is a fundamental element of these courses.

The faculty of Mechanical Engineering is one of the largest faculties of the university, with a yearly enrollment number of about 200 students. The nominal duration of the course is five years.

The main reason for the decision to design a new program was the decrease in the number of students that completed their first year of study within the prescribed time: over the period 1988-1993 the percentage dropped from 48% to 32%. And after the first basic year, student progression was also below the norm. This was interpreted as a signal that the the classical approach to education failed to motivate the students to spend the necessary amount of time on their studies. Therefore, the faculty decided that a new approach was needed. The rationale of the design of the new curriculum was to create a more motivating program, that would stimulate the students to spend more time - at the right moment - on their study tasks. This was supposed to lead to a higher percentage of students that would study 'in phase' with the scheduled program.

In the second paragraph a description of the new program as well as the old program is given. The third paragraph is about the most important element of the new curriculum: the project. It describes the study load of the projects, the character of the projects, the project group, the role of the tutor and the assessment of a project. In the fourth paragraph general conclusions about the results of the new curriculum are stated and a more detailed account of changes in student progression is given. Finally, the fifth paragraph mentions some problems we are still experiencing in the new program.

2. Description of the Old and New Program

The old program

To give you an idea of the extent of the change, you need to know a bit more about the old program. We will concentrate on the first and second year of the curriculum, because this part has transformed most. Each year was divided in three trimesters of three to four months. Different courses were given in each trimester, with exams of all the courses at the end of the trimester. Student-activities in these courses were: attending lectures and tutorials, doing lab-courses, and self-study - reading the textbooks and preparing the lectures and tutorials. As mentioned before, the first two and a half years of the curriculum are basic: it consists of introductory courses in Mechanical Engineering, and students also have to do quite a number of courses in mathematics. To the student, all these courses often did not have any visible relation to each other. Moreover, because of the rather traditional, teacher-centered approach to education, they were not asked to perform activities in which they would learn to use the knowledge and skills in a real-life context.

A number of problems arose from this situation. Firstly, a program like this is not very stimulating and motivating for students: they have a rather passive role and there isn't a great variety of learning activities. Secondly, the basic program does not reflect the working practice of an engineer. Students do not experience what mechanical engineering really is, until the last (fifth) year of the curriculum in which they do their graduation project. From a learning perspective this is too late: gathering separate pieces of knowledge in a context that is not related to contexts in which the knowledge eventually has to be used, is in itself not sufficient to be able to analyze complex, real-life problems and design and realize solutions to them (Resnick, 1989). In addition the students had insufficiently developed skills in communication, particularly in report writing. To prepare students for the aforementioned tasks, a series of carefully designed learning experiences in which the students tackle realistic problems of increasing complexity is necessary (Brown, Collins and Duguid, 1989). There is another reason why an early experience with such tasks is preferable. The first year of the curriculum must have a selective function: in and after the first year a student must be able to decide whether he or she is able to do the course, and whether he or she is interested in the kind of work a mechanical engineer usually does. The tightening regulations of the Dutch grant system don't give students much time to switch to another course in case of a wrong, first choice.

The new program

The new curriculum of Mechanical Engineering is inspired by the educational philosophy of the University of Aalborg in Denmark (Kjersdam & Enemark, 1994). It was argued that the Aalborg method of project-based education had the appropriate characteristics for attaining the goals of the new curriculum. Firstly, the inclusion of projects in the curriculum leads to a greater variety of activities the students have to perform, which will make it more motivating. Secondly, projects can be used very well to teach the skills of designing products and processes - a connecting theme running throughout the complete curriculum of Mechanical Engineering at Twente.Thirdly, projects can make the coherence in the study-program visible: the connections between different courses become more evident. Fourthly, projects can play an important role in actively developing communication skills, including the value of working in teams.

The new curriculum is of course not a copy of the typical Aalborg curriculum, because it is not wise simply to take over an approach from one country (with all its cultural norms) and transplant it in another country with quite different cultural norms. Thus in Twente we have therefore freely adapted the Aalborg experience to our perceptions and our culture in a Dutch university.

In the new program the first year is also divided in three trimesters, in the second year there are two semesters. But the structure of the trimesters and semesters has changed to a block-organised structure. This block-organised structure means that courses are given within relative short periods or 'blocks' rather than spread over the entire trimester, as in the past (one block lasts about four to seven weeks). It also means less courses in the same period. This is supposed to lead to less 'competition' between the different courses. With 'competition' we mean the following. In the traditional system, a student often cannot spend the necessary amount of time to prepare a lecture, tutorial, or lab course, because there are quite a number of other lectures etc. from other courses that also need to be prepared. The result is either superficial mastery of every course, or good mastery of a few courses and the neglect of other courses. Another feature of the block-structure is that the examinations take place immediately after the end of a block. In the traditional trimester, students often postponed studying because the examinations were only at the end of the trimester. The block-structure must stimulate students to study more regularly and synchronous with the program. Students are expected to spend 45 hours per week on studying.

Other elements of the new program are projects, project-supporting courses and theory courses. Each trimester or semester contains a different project, that covers about 40% of the study load (a trimester has a study load of about 560 hours). Because the projects are the key-element in the innovation, a separate paragraph is dedicated to them in this paper (see the following paragraph). In the remainder of this paragraph we will focus on a description of the project-supporting courses and the theory-courses.

The knowledge and skills needed to achieve a satisfactory project result, are taught in the project-supporting courses (20% of the study load). These courses already existed in the old program, but the order in which they are given now is sometimes changed, the contents are adjusted to the project and the traditional written examination is often changed to a verbal examination, integrated in the project assessment. The theory courses (40% of the study load) mostly don't have a relation with the project. The mathematics courses are an example of this.The contents and form of examination of these courses are often the same as in the old curriculum. In some cases, part of the contents are moved to another course because of the block-structure or the projects.

3. The Projects

Study load of the projects

The fact that each trimester (or semester) in the first two years contains a project of substantial study load, makes the Mechanical Engineering curriculum unique at the University of Twente. Each project starts at the very beginning of a trimester (or semester) and has an absolute deadline at the end of it. Thus the students have to get used to working to a deadline from day 1: if they don't do this, they are unsuccesfull.

The study load per student of each project in the first year is 220 hours on average; in the second year it is 320 hours and 400 hours. In the weekly time-table the number of hours available for project work gradually increases during a trimester. There are two reasons for this. On the one hand, in the beginning time is needed for the project-supporting courses. On the other hand, this reflects the natural process of doing a project.

The character of the projects

Each project is based on two disciplines within Mechanical Engineering. Most project assignments are about designing a product. In figure 1 you can read some descriptions of different projects. In addition to skills concerning the mechanical engineering aspects, students develop skills in planning, working in groups, running meetings, reporting results and discussions, presenting the work of the group, and defending the work done.

One project has a different character: it is a sort of business-game in which students have to run a production company (becoming a manager is a probable job-perspective for mechanical engineers).

Figure 1: descriptions of some projects

Project A (trimester 1.1): Focuses on production techniques (casting, forming, joining), technical drawing aspects of design (drawing conventions, fits and tolerances). A project for familiarisation of graphical techniques, including a CAD programme (Vellum). In that all phases of a project are explored from problem analysis through to adaptation of a prototype for large-scale mass production, this project gives a good orientation to the discipline of mechanical engineering. The end result is a prototype to be demonstrated in action: a prize for the best design. Examples of concrete project assignments, based on these objectives, are: designing and constructing a can crusher for domestic appliance; designing a punching machine for the punching of symbolic characters.
Project D (semester 2.1): The emphasis is on aspects of design and material choice (metals and plastics). Aspects of tribology, production technology and mechanics are included. More specifically the project embraces aspects such as choice of degrees of freedom, static behaviour of a power drive system, choice of power train components, stiffness and damping behaviour on the basis of a simple dynamics model, design of frame constructions in plates and beams, calculations of stiffness and strength of metals and fibre reinforced plastics, and experimental testing for material properties. Examples of concrete project assignments, based on these objectives, are: designing some components of a car driven by electricity; designing a portable injection moulding machine for moulding badges
Project F (year 3): The design of a mechatronic product (mechatronics is a synthesis of mechanics and electronics) in which precision displacement is important. Thus precision engineering, electronic control, advanced dynamics, automation, finite element modelling, are important. The product is to be made and tested. The academic level is high and there is substantial interaction between tutors as well as between students. Feedback of research ideas into the teaching makes for an extremely lively atmosphere. An example a of concrete project assignment, based on these objectives, is: designing a device for rapid precision displacement of a laser bundle for a machining operation.

The project group and the tutor

In a project a group of six to eight students work together as a team. Except for the first project, the students have to compose the project groups themselves. Each group has its own project room inclusive of computer hardware and software, which is in principle accessible 24 hours a day, seven days a week. They are supervised by a tutor, a member of the staff. The role of a tutor is ideally to keep the group on the right track in a non-directive manner, to monitor the process and progress of the group, to give suggestions, to give clear and constructive feedback on intermediate products, to be stimulating and finally to judge the project result.

Assessment of the Projects

Assessment takes place on the basis of the project report. Bearing in mind that the project has an integrating character embracing several project-supporting courses, the assessment must also recognise this. The project examination is not simply the sum of the separate verbal or written course examinations.

The project report is first assessed by the tutor and other examiners (the lecturers of the project-supporting courses). The group is informed about the mark and receives feedback on good and bad aspects. The latter enables them to prepare themselves a bit for the second part of the assessment, the verbal examination.

Each group gives a verbal presentation of the project work and its conclusions (this demonstrates skills of communication which are also assessed). Each member of the group must report on something substantial. Present are all members of the group, the examiners and anyone else who is interested. After the presentation and a short break, basic and detailed questions are asked covering the contents of the project report. Each student should in principle be able to handle questions about any aspect of the project because the group as a whole has responsibility for the work done, not just the individual who did the detailed work on a particular aspect.

After this session, the examiners decide together what mark each student gets. If the knowledge demonstrated by a student about the project and the project-supporting courses is insufficient, he or she has to do a supplementary examination later on. Each student receives an individual, final mark that is the weighted average of the mark for the project report and the marks for the verbal examination of the project and the project-supporting courses.

4. Results of the New Curriculum

In reporting the results of the new curriculum, we want to make a distinction between the results on different levels: the students, the staff, the specialist groups within the faculty, and the faculty itself. Some of the results are intended (these are mainly the effects on the student-level), and some of the results are (positive or negative) side effects (for example the effects on the specialist groups and the faculty). First we will state the general conclusions and after that we describe the most important results in more detail.

General conclusions

The general conclusions we have reached after three years of experience with the new program, are as follows:

Student level:

1. Students are well-motivated to work harder and achieve success.
2. Student progression rate in the project-based education is more rapid and decisive than with the old classical approach. In the first year however, there is not yet a sufficient improvement in the progression. But, unsuitable students are identified early on and encouraged to follow other more suitable courses. Therefore, the progression in the second year of the group of students as a whole did improve.
3. There remain some theory courses where the success rates of even the able students is not satisfactory.

Staff level:

4. The majority of the staff are in general positive about the new curriculum and satisfied with the level of knowledge and skills the students reach in the projects.
5. They are also enthusiastic about their new task of supervising project groups: it gives them more insight in the capabilities of the students then in the old curriculum, in which the frequency and intensity of the contact between staff and students was not as high.
6. The third year project is an interesting illustration of the possible impact of a project. There is widespread agreement that this advanced level project has stimulated the students and staff to a most beneficial extent. Staff who might have been rather sceptical about project-

based education are now highly enthusiastic. Staff groups from the two chairs contributing tutor support have formed very strong new bonds with ambitions for working together more closely on both teaching and research programmes.

Specialist group level:

7. The involved specialist groups within the faculty had to revise their educational program of the basic part of the curriculum. In earlier years, the educational programs of the specialist groups consisted of a number of separate courses given by different lecturers. The lecturers often didn't know much about the contents of the courses of their colleagues. But now, designing the educational program is more a matter of teamwork: the members of a specialist group work together in designing the project assignment, supervising project groups and assessing the project results. We think that the coherence in the educational program of a specialist group has become stronger by this.
8. Those specialist groups who have not worked in the projects feel distinctly left out, and there is the expectation that their lack of contact with the students will probably mean that the students will not choose to enter these groups when they look choose their specialisation for the last two years of the MSc programme.

Faculty level:

9. Because of the fact that the project assignments are based on two disciplines within mechanical engineering, two different specialist groups have to work together in designing the educational program of a trimester or semester. So the argument made about the beneficiary effect on specialist group level is also valid on faculty level.

But..........., although we want to stress that the general conclusions are positive, we also have to admit that not all goals have been reached yet and that there are still some matters of concern. More about that in the following paragraph (5.). First, we want to elaborate a bit more on the results at the student-level.

Student progression and learning results

Student progression is measured as the number of study points a student has obtained (the study load of courses and projects is expressed in study points: one study point is equivalent to 40 hours of work).

In figure 2, the progression after one year of study time in the new curriculum (cohort 94[a] and 95) can be compared with the progression of the students in the old curriculum (the average of three cohorts, 91, 92, and 93 is plotted in the graph). The percentage of students who are fairly well on schedule after the first year (fairly well on schedule means: having obtained at least 80% of the study points) has not yet increased after the curriculum reform. So that goal of the innovation has not been reached yet. But in comparison with cohorts 91, 92 and 93, there were more students in cohort 94 who studied exactly at the nominal tempo (having obtained all study points; not in the graph). The percentages are: cohort 91: 37%; cohort 92: 28%; cohort 93: 33%; cohort 94: 46%; cohort 95: 37%. And there is another effect to be observed: the percentage of early drop-outs is increasing. Also, probably related to this, the percentage of seriously delayed students has decreased substantially. Thus, the project-based and block-organised education indeed leads to an earlier sorting out into suitable and unsuitable students.

[a] A cohort is the group of students of the same year of study; for example: cohort 94 are all the students that started in 1994.

In figure 3, the situation after two years of study time is presented. In the new curriculum, a lot more students were on schedule at that moment and there were no drop-outs in the second year. Throughout all the courses of the university it is a well-known phenomenon that student-progression slows down after the first year of study time. So this is an important improvement.

An interesting and important question is of course: why is there no improvement in progression during the first year of study time? One possible explanation is that the students need time to get used to studying in project-based and block-organised education. In the Dutch system of secondary education, they often have not learned to work in a self-directed way and to work in groups[b]. In the old curriculum this problem of abrupt transition after leaving school was also present of course (more freedom, more difficult subjects, having to work harder, etc.). But it's possible that the project-based education at first puts an additional pressure on the students: in planning and spending their time they have to find a balance between the project work and the individual work (studying for the other courses). Often, the project work is more fun and seems more urgent, so the other courses are neglected. It can be argued that after one year of experience in this system students are better able in finding and maintaining a proper balance, and that from that moment student progression is positively influenced by the new system.

In addition to the quantitative results, we can also report some qualitative results about the skills and attitudes of the students that are the result of their project work. The following are subjective impressions: we are trying to measure these statements in a more scientific way.

- Students are more self-standing and self-starting. They seek information for themselves - e.g in the library or on Internet, telephone firms, approach teaching staff. They know there is more to engineering than buying a standard solution.
- Students are well-prepared to work in groups, divide tasks, to organise and run meetings, to give and receive feedback, to report verbally and in writing.
- Students have learned to make thorough use of the possibilities of computers, such as word-processing, spreadsheets, graphics packages, as well as specialist software programmes.
- Students are in a good position to write a good well-constructed coherent report about their project work, and to give a clear overview of it verbally to a group of assessors and other interested parties.
- Students have learned to plan their work and divide their time in an efficient manner in order to get a job done within a deadline.
- In a group-working mode, some students are able to reach a solution to a given problem which bridges the expertise of several teachers.
- Students probably have less factual knowledge learned by heart, but what they do not have they can readily look up and then apply to solve problems in the correct manner.
- Students have the confidence to approach teachers and others in a proper and professional manner.

5. Problematic Issues

In this paragraph we want to discuss some issues that are still more or less problematic in the new program. These issues are: (1) the assessment of the projects; (2) the supervision of the

[b] In this context it is interesting to know that at this moment a lot of changes are going on in secondary education, initiated by the Dutch government. The goal is to establish a learning climate in which the traditional teacher-centered approach is shifted to a more student-centered approach.

complex projects after the first year; (3) inflexibility of the program and (4) the courses that are not integrated in the project. To each issue, a separate paragraph is dedicated.

Assessment of the Projects

The current set-up of the verbal part of the project assessment is not very efficient and satisfactory, because it asks a lot of staff time and it yields little information about the acquired knowledge and skills of the individual students in the project group. Each verbal examination costs two or three members of staff four hours plus preparation and reading reports. With 20 project groups, this can add up to a total of about 200 to 300 hours, exclusive of preparation and reading reports. As mentioned before, the project-supporting courses also have to be assessed during the project assessment. In practice, the time available for each student in the group to demonstrate his or her knowledge of the project and the courses by answering the questions is at the most half an hour. Often, this is not enough to get a good indication of the capabilities of the student. In addition the examiners don't have much experience of this way of assessing students. In the past, every course had a written exam. The exams mostly consisted of a number of problems that had to be solved by doing calculations. This way of assessing is fairly easy for the examiner: you just check whether the calculations were executed correctly and give the student a mark, based on some formula. Some examiners that are involved in the verbal project assessment have difficulties with thinking up the right questions; they cannot use the same sort of questions that were asked in the written exams. Also, they have to improvise during the examination; one can prepare some questions in advance, but it will always be necessary to think up questions on the spot, in reaction to the students' answers. Furthermore, it is the intention that the questions are related to the project work: this can show whether the students can apply the knowledge from the course. Thus, the examiners also need time to learn this new way of assessment. We are not completely sure whether the problem will be solved when the examiners have more experience with this way of assessing. Perhaps a different set-up is needed.

Supervision of complex projects

After the first year, the projects become more complex and cover more subjects in mechanical engineering. But the tutors are usually specialized within a particular subject, and don't necessarily know the ins and outs of all the subjects in a project. The problem is that students often expect them to be. Although this is understandable, not all tutor can come up to these expectations. What then is reasonable to expect? We think a tutor must know enough about the basics of a particular subject, or must be willing to learn about them, must understand the questions students ask, and must know who in the faculty is the appropriate person to answer the questions, and can recommend useful literature etc.. Tutors also must be willing and able to explain the basics of their specialization to other tutors, if needed (tutors are often lecturers of the project-supporting courses). Before and during the execution of a project, the tutors have to inform each other, for example by means of mini-lectures, about the knowledge the students have to use in the project, so that the other tutors have a good basic understanding of all the subjects. But, in practice this requirement is not always met. This causes irritation and frustration in the students, and too much pressure on the experts because all students come to them with their questions.

Inflexibility of the program

Both the block-organisation and the regulations of the project-based education make the new program somewhat inflexible. In courses that are block-organised, there are for example three lectures and two tutorials in one week. What happens if a student becomes ill? There is hardly any time to eliminate the backlog, and there is also project work to be done. So this sometimes causes too much stress in the students.

A regulation concerning the projects is that a student needs to have passed the preceding project to be admitted to the following project. In addition, he or she must have passed a certain number of theory courses. When someone doesn't meet this requirement, he or she has to wait until the next year. This regulation may seem rather strict, but it serves the purpose of selecting the suitable and unsuitable students in an early stage. And if someone can't meet the requirements, despite having worked very hard, it will be clear that he or she is not able to do the course. But there is a problem if a student who is in principle suitable, can't meet the requirement because of illness or other difficulties that have nothing to do with his or her capabilities. A possible solution to this problem is to make an exception for that student. But of course the regulation is not arbitrary: the idea behind it is that a student needs to master the knowledge and skills that have to be learned in the preceding project, because they are prerequisite knowledge for the next project. Also, to the other members of a project group it's not fair: it could be disadvantageous to have someone in the group who lacks the necessary knowledge.

Thus, for the students who can't keep up with the programmed curriculum, but do not drop out, a sort of alternative program has to be organised. This costs extra staff time and for the students it is often rather frustrating and extremely disappointing to be 'separated' from their fellow-students.

Theory courses

The exam results for some of the theory courses are not much better than in the old curriculum, despite of the block-structure. This is a serious problem, as it not just concerns the less able students, but also the able students. It seems that rearranging the courses into a block-structure is in itself not a sufficient condition to improve the succes rate.

It is possible that the projects have a negative influence on student motivation to study for the theory courses. The contrast between the two is high: project work is almost always more motivating than attending the lectures and the tutorials and studying the abstract contents of the textbooks. Furthermore, there's the problem of possible group pressure. When a student needs relatively more time than planned to pass a theory course, the project work may suffer. But probably a good-willing and social-minded student doesn't want to neglect his or her project tasks. So the competition between the theory course and the project is often easily won by the latter.

The second problem (group pressure) is not easily solved and probably it's not the main reason for the disappointing success rates. The main reason is the first problem: some of the theoretical and abstract courses are not motivating enough. At the moment this is being handled by a fundamental review of the teaching of these courses, and we are confident that the situation will improve.

References

Brown, J.S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. Educational Researcher, 18(1), 32-41.

Kjersdam, F., & Enemark, S. (1994). The Aalborg Experiment. Aalborg: Aalborg University Press.

Resnick, L.B. (1989). Knowing, learning and instruction. Hillsdale: Lawrence Erlbaum Associates.