THE ROUTE TOWARDS A SUSTAINABLE DESIGN-IMPLEMENT COURSE

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Abstract
The paper deals with sustainability aspects of design-implement courses in engineering education. Conclusions from a course at KTH that has proven to be sustainable are presented, based on experiences from seven years' course development. Design-implement courses are often assumed to be expensive but the presented paper illustrates that they can be united with sound economics. Enhanced student learning can be achieved but furthermore, the course can also contribute to increasing enrolment through good reputation and positive publicity among students. Some aspects of examination are discussed where the focus is on demonstration of individual abilities although most of the course work is performed in a group setting. In the example course, peer assisted individual formative and summative feedback and grading is used in a way that deeply involves the students. A very advantageous effect of this is that the students develop a thorough understanding of the rationale of the assessment scheme and thereby can place their own accomplishments in perspective. One important driver towards a sustainable design-implement course is to focus less on the details in the project work, in favor for the details in the course design and presentation.

Keywords: Sustainable, Project, Course, Engineering, Education

Introduction

This paper is based on experiences and conclusions made during the development and running of a final-year design-implement course in an MSc engineering program. By a design-implement course we mean a course that contains elements of problem identification and formulation, solution identification and execution, as well as a physical realization and verification of the solution. The course concept has several obvious pedagogical benefits in that it allows students to achieve hands-on experience from activities that relate their theoretical knowledge to real problem statements. That is not mainly a matter of providing concrete examples to help students understand theory but more a matter of illustrating the validity and applicability of theory, and the limitations thereof, in real non-idealized situations. The course is also project-oriented in the way that students work together in a relatively large group to solve a rather complicated task during two semesters. The project task confronts the students with some of the complexity in real engineering problems, where things could not easily be broken down and solved as separable sub-problems but have to be handled as a system of mutually dependent parameters or activities. The students' motivation, curiosity and enthusiasm are enhanced when they feel that they need knowledge to reach a goal or work around a problem, and when they notice that the knowledge and skills they have gained can truly help them to accomplish things and solve unfamiliar problems it gives them great satisfaction (see Fig. 1). The project task also trains personal and interpersonal skills and actuates numerous aspects of the engineering profession, which are difficult to appreciate without real first-hand experience.

Figure 1. A satisfied student during sea trials, April 2007

This type of course is often assumed to be expensive, teacher dependent and considered impossible to combine with fair, individual assessment. The term expensive is often used in terms of teacher time per student credit, premises requirements, consumables, et cetera. Worries about teacher dependency are sometimes expressed where instructors are believed to possess a specific combination of experience, skill, and enthusiasm, and that the survival of a certain course thus is very vulnerable to ceasing commitment of such individuals. The challenge to assess students individually while working in a project setting has also been considered a drawback for the type of course presented. These worries are probably motivated since they ever so often are based on first hand experience of people who have been involved in university education for some time, but that is not to say that the outcome couldn't have been different in the cases they refer to. We will here share some of our views on sustainability and elaborate on the pedagogical ideas behind the course we have developed. We will finally show that these issues are actually connected in a constructive manner.

The experiences presented in this paper may not be generally applicable to design-implement courses as a class. It is not the fact that it is a design-implement course that makes the course successful but rather that the course is designed and handled in a way that makes it work. The philosophy behind the course at hand has always been that the students should be invited and encouraged to move from the passenger seat to the driver seat, in small as well as fairly big matters. And it is really this principle that has proven to constitute a main key to success and sustainable developmen.

Background

In 2000 a design-implement course was launched at the Royal Institute of Technology (KTH) as part of the CDIO reformation of the Vehicle Engineering program [1, 2]. The course was outlined from the standpoint that an engineering education should not only provide courses in engineering topics but also foster professional attitudes and behavior. A capstone course was developed where experiences and knowledge gained from other courses was to be utilized through application on concrete problem statements. The outcome from the course work should not become a paper-product but result in a real physical implementation of the work performed, allowing for verification of analysis and design solutions.

By letting students work together in relatively large groups to solve a given problem statement, personal and interpersonal skills can be developed and trained in an authentic technical context. This aspect accentuates the importance of efficient project management in terms of e.g. clear communication, distribution of information, planning and follow-up, decision-making, et cetera. During the first years of its development the course could rightfully be accused for being more expensive than the average. It is however not obvious that it was more expensive to develop than an "average" final year project course in an engineering program. Somehow it is reasonable that a final-year course is a little more expensive than the average course in a curriculum. There are also other values that matters than the cost per student credit, such as

- Satisfied students promote their choice of education (Figure 2)
- Satisfied teachers remain motivated
- Satisfied employers recognize the education and the environment where it is developed

During the last few years it has also been established that the course is not more expensive than comparable final year courses and we will continue to explain how that is possible.

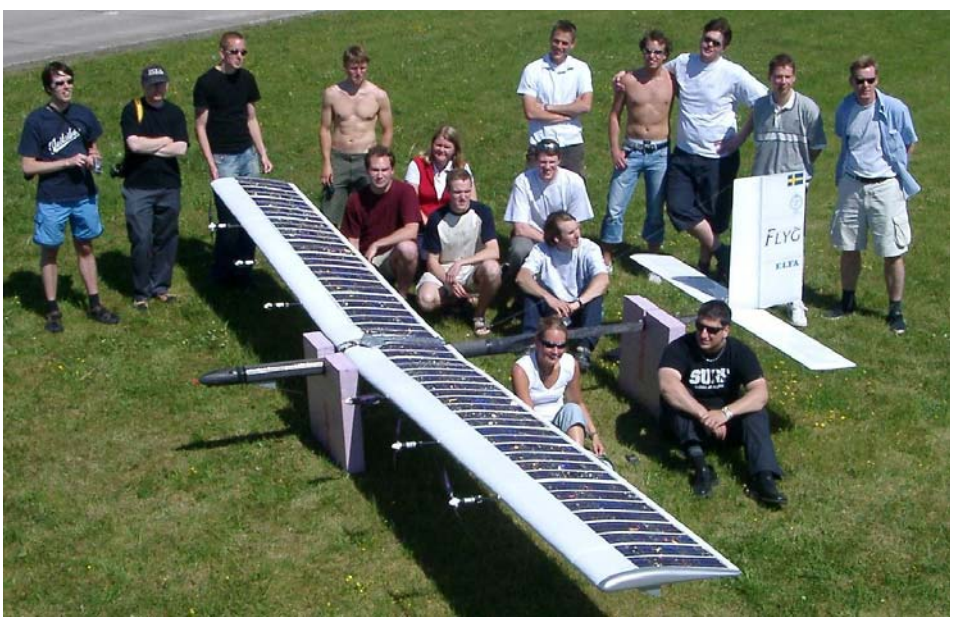

Figure 2. Proud students likely to promote their education

What is Sustainability?

The concept of sustainability is versatile. It could imply conservation of a certain educational module independent of continuous financial support, specific hardware or premises, involvement of key individuals or external resources. To us a sustainable activity secures continuity, maintenance and development rather than conservation. We argue that a good course should have clear goals and be founded on sound pedagogical ideas. The goals and ideas do not necessarily need to be invariable over time but could themselves be subjects to development. In the following we will discuss some factors that need to be managed properly in order to make a course sustainable.

Cost

In principle all costs related to a course could be broken down into the following categories:

- Teacher time
- Premises
- Equipment
- Consumables
- Outsourcing

The teacher time is simply the number of hours teachers spend on the course and this effort is utmost an economical matter for the faculty. One way or the other the university compensates its teachers for their teaching duties and the level of compensation dictates how much time the teachers could afford to spend on the course. The costs for premises are managed differently at different universities. Some courses have access to large premises to a reasonable cost while others are constrained by relatively confined quarters and/or have to pay substantially for the space they occupy. Since the circumstances vary the need for efficient use of premises and the related costs are more or less of an issue for different courses. At KTH the rent is considerable and dedicating space for a specific course is somewhat extraordinary. For the course described in this paper the cost was motivated by deciding to use the same space for several activities in the course, e.g. teaching, meetings, seminars, basic manufacturing and assembly. The premises also constitute a resource for the students outside course time since they could use it as a meeting place and as study space. Some hardware is usually needed in design-implement courses, typically tools for manufacturing, a couple of computers and related equipment. The cost for hardware could also vary substantially for different courses but expensive hardware is generally not likely to be purchased solely for use in a course. The costs for consumables could also vary depending on what is produced in the course. Outsourcing refers to all services that need to be found outside the university. In many cases students can find sponsors who are willing to support the project in various ways. Common for most of the listed costs is also that they could be adapted to available resources through proper dimensioning of the course activities. Quite a lot could be achieved with relatively small means and the pedagogical benefits are by no means dependent on fancy equipment or expensive materials, although some people tend to be more impressed by the presence of such. We will return to the economical aspects of design-implement courses in a later section of the paper.

Competence

Obviously, involved faculty need to have necessary knowledge and adequate pedagogical training to give a specific course in a fruitful manner. In most courses at universities the teachers develop the necessary knowledge as part of their own research or simply by studying the topic at hand. In a design-implement course parts of the necessary body of knowledge are theoretical and rather archetypal for university faculty, but some are not. For instance, practical design, field experiments, manufacturing aspects, verification plans and practical project management are areas not likely to be mastered by a single staff member. The course management does however not need to master every detail of the course contents. One option is to broaden the knowledge of the involved teachers enough for them to feel comfortable instructing the students. This is many times sufficient but it is sometimes better to look for, and use, existing knowledge when easily available. Locating and using existing knowledge is also an important competence for the engineers we educate! By involving experts from other fields, e.g. through short dedicated teaching modules or seminars, a lot of value could be added to the course, and at a reasonable cost too. A great benefit with the latter approach is that an expert would keep the taught material updated, be able to answer more elaborate questions and guide the students to alternative sources of relevant information. It is also better in line with our perception of higher education to have true experts teaching their topics. Over the years we have involved faculty from other fields as guest lecturers in our course. It is obvious to us that their contribution generates interest among the students and support for their work at a level we could never reach if we tried to teach those modules ourselves. We also involve our technicians in some of the practical work the students perform. They provide support through practical advice and by sharing their views on various design solutions, and they educate students to handle some of the equipment they need to use in manufacturing and testing. The last source of competence is the students themselves. Even though it varies from one cohort to another and being a bonus rather than something one could count on when planning the course, a large group of students generally possesses all kinds of valuable experiences, expertise and contacts. Over the years we have seen several examples of students contributing to the project with things and in ways we could never have foreseen.

In addition to the necessary topic-specific competencies, faculty need to have a certain pedagogical perspective in order to create a course in which the resources are put to efficient use from a learning perspective. Developing and running a design-implement course offer plenty of opportunities for faculty to increase their pedagogical insights and to our experience this development could be amplified considerably through support from regular staff development activities provided by the university. Some of the strategies used in the present course have matured during long-term collaboration and discussions between responsible teachers and teaching and learning specialists. The collaboration has resulted in informed course development as well as joint publications on the pedagogical discoveries made, e.g. Edström et al. [3].

Motivational Context

A third component of course sustainability is its motivational context. How is the enthusiasm of the involved teachers maintained? Is there clear support for the course among students, involved teachers and other faculty? Do teachers receive recognition for the work they perform and are they challenged enough to remain motivated? This issue is connected to that of cost, as it would be impossible in the long run to give a course that requires more teacher time than the university can support. It is not a sustainable situation if every year faculty would need to put in more hours than could nominally be expected. It is also connected to the pedagogical competence of faculty. When faculty have a clear view on what actually contributes to student learning, they can spend their time in a much more efficient way.

Enabling Succession

Another aspect of sustainability is succession. Are enough teachers involved to assure necessary redundancy and enable that management of the course could be passed on to others? Are course activities dependent on the involvement of external resources, competences or key individuals?

In a quality course the responsible teachers should be able to clearly express and motivate the goals and anticipated learning outcomes as well as providing some documented course material and describe how the course is designed and delivered to the students. Based on this it should be possible to pass the responsibility for the course on to somebody else, who obviously would be helped by having had previous involvement in the course too. A course is always shaped by the teacher(s) who give it but that does not imply that nobody else could do the job properly. In order to avoid dependence of key individuals, it is a good strategy to involve more people.

All is Well that Ends Well

Even if the worst thing would happen and a successful course would cease to exist, how bad could it be? Is it entirely bad that a course only lives for a limited time? The course might need to be replaced and the educational program risks to loose some recruitment. However, if the course has lived for a while and faculty and students were happy with it while it did, how could anything be negative with that but the fact that it has ended? It most likely trained and taught the students, developed the involved teachers and even inspired others. No, the only bad thing about a good course ending is that it ends. It cannot be close as impairing to an education than it was beneficial while it existed. Thus, any program manager or dean who are fortunate to run an education with a set of good courses should not grieve the eventual loss of a course but rather stimulate the upcoming of new ones.

The Expensive Course

The term "expensive" calls for some elaboration. It could express the actual cost for getting something done being somewhat higher than acceptable, in terms of money. Unfortunately, in a short-sighted economical reality, this cost alone could disqualify even the best of pedagogical ideas without even putting it in relation to the potential profit on a little longer term. We will deal with the issue of expense both from a broader view, where the value of different things are discussed in relation to the concept of cost, and from a more strict economical standpoint, in order to satisfy those who may have to focus more on accounting. The costs for course development have been discussed previously and the conclusion is that such costs are inevitable if a new course is to be introduced, no matter what type of course it is. So let us now focus on the economical aspects of running a design-implement course in continuance. Obviously the costs are important and need to be kept under control, that is however not the same as always keeping them to a minimum. It is more important to be aware of how the main costs are distributed, which costs matter and which don't, and most importantly which costs pay off. What has to be remembered (and this is a universal problem!) is that costs only constitute one side of the economical act of balance, or even revenue. Fighting costs unconditionally, at all times, tends to suffocate both the activities and the enthusiasm of the people involved. As a university we have a great product to "sell". Bright people come to our educations and leave it as fresh but skilled engineers. It is a highly lucrative investment for external organizations to show interest in and support student projects. The obvious reason is that it might make students interested in applying for job opportunities at these organizations but it also generates great goodwill in the sense that the students will be left with a positive impression of the organization that will remain for quite some time. In general the costs involved for companies, institutes or authorities sponsoring or supporting student projects are insignificant. The long-term return on investment is potentially considerably larger. It is however unfortunately difficult to measure the benefits in accounting so there could be a pedagogical task involved in explaining these values to external parties.

Of course the university needs to watch over its integrity and make sure that the relation with external parties is truly symbiotic in the sense that the quality of the education is strengthened and not damaged by their involvement. But again, there is so much to gain for the involved external organizations that this should not be a problem. The ideal situation is if a state could be reached where there is mutual interest between the university, its students and external stakeholders to support each other. The university provides students with education and professional training, and supplies organizations with well-educated engineers. The students help the university to promote the education and thus support sustainable recruitment, and they offer the organizations ways to expose their business to future engineers. The organizations provide the university with relevant problem statements and support the students with feedback and means to make their projects even more spectacular, see Table 1. An obstacle to involve external parties is that faculty seldom has the time to promote their education externally and encourage external parties to pay interest to what the students are doing. However, since it is recurrently in the interest of the involved students to tie sponsors to their projects, involved faculty could with a little patience build up a network of external contacts in cooperation with the students, over the time of several projects.

Table 1. Mutually supportive relations between university, students and external organizations, in the context of design-implement project courses.

To **From**	University	Student	Organization
University	–	Education Professional training	Skilled engineers Contact with research
Student	Promotion of the education Recruitment	–	PR Contact with potential future employees
Organisation	State-of-art industrial problems Ideas for research	Contacts Realism Feedback	–

As an example, one of our projects was approached by a company that wanted to become a sponsor, not since it had commercial interest in the project but since it recognized that the project expressed an innovative, environmentally friendly, "high-tech" image it wanted to buy in on. The people involved also realized that the project would receive attention among other students – their future employees – and wanted to have their brand associated with the project.
We have also seen examples of companies being specifically and explicitly interested in recruiting students from a certain project, in one case based on specialized technical knowledge but in others just based on the fact that the project group had made a strong impression.

Correlation Between Pedagogical Outlook and Good Course Economics
We have already touched the basis for prosperous development of a course and we will now specify the recipe in greater detail.

"The Magical Principle"
Since the start of the course it has been the outspoken goal to make the students responsible by handing over ownership of the project tasks directly to them. Initially, the rationale was mainly to make the students involved in a way they would be in a real professional situation. However, as the course has been developed this single principle has proven to be much more constructive than we realized when we first made it up. In practice it means that virtually all student activities within the course are motivated from what is needed to solve the task. Reports are written primarily to share information from investigations performed in subtasks with the rest of the group, and to enable traceability and means for evaluation and verification of the quality of the work performed. Project plans are made in order to efficiently manage and monitor the budget in terms of available man-time and financial means. This may sound self-evident but it is not in line with how such activities are normally presented to the students. It turns out that the students are so accustomed to deliver work with the sole intent of demonstrating learning to the faculty that producing something that actually serves a real purpose for them feels unfamiliar. Typical dialogs between students and instructors at early stages of the course could be:
Students: - How do you want us to write the project plan?
Instructor: - We don't want anything with the plan. It is *your* plan. What do *you need* to include in the plan in order to make it useful for the group? Here is an example and some references to get you started.
Students: - When do you want us to have the report ready?
Instructors: - When does the group need the plan in order to make decisions necessary to proceed?
Obviously one could not run a course by letting every question that is raised bounce back to the students and the project groups are of course supported with teaching, coaching and guidance in parallel with the work they perform. However, we avoid questions of the type "What are we supposed to do?" by referring back to the task formulation and encourage the students to think for themselves and take initiatives rather than expect somebody else to do it for them. This attitude sometimes startles the students and it can take a while before they understand, accept and adapt to what is expected from them. However, once the shock is overcome they rapidly grow to the task and soon it becomes more recurring that teachers are stunned by students' achievements than students by teacher attitudes. The students mature tremendously during the course and one could literally see their development from the role of university pupils to professional engineers. From a pedagogical perspective the fact that the students are consistently encouraged to tackle the challenges themselves increases their learning. The teachers advise and support initiatives from the students instead of planning and guiding the work in detail. Thereby more of the teachers' time is spent on the students when they feel in need of knowledge and thus put their full attention at achieving it.

About Individual Assessment in a Group Setting
Although the course participants are working in large groups we have chosen to grade each student individually. Fair and valid assessment of individuals in a group setting is not a trivial undertaking. This is one area where faculty’s competence has developed greatly as the course has

evolved, through continuous support from teaching and learning staff. The grading process is quite involved and utilizes elements of peer assessment, described in greater detail by Edström et al. [3]. In many project-oriented courses students are either graded binary - pass or fail - or graded collectively group-wise. We have chosen to measure and assess the performance and achievements by individual students and the developed procedure is indeed somewhat time-consuming. However, parts of the assessment procedure are defined as mandatory course activities in which the students are expected to spend a certain amount of work. The students are invited and encouraged to formulate and share their own views on the principles, rationales, indicators and taxonomies for assessment, in discussions and reflective exercises led by the instructors. Constructive feedback is introduced and exercised as part of the process. Aspects like relative versus absolute grading, quality versus quantity and similar related matters are discussed thoroughly and by the end of the course the students have reached a quite sophisticated level of appreciation of how and why assessment is complicated. Some readers might feel a little uncomfortable with inviting the students to discuss principles for assessment since it could give them the idea that the grades they finally receive also are open for discussion. Not only could it promote the students to question the judgment of the instructors but also provide them with the knowledge to drive quite educated campaigns on the matter. This is however not at all our experience. On the contrary, the students' awareness of the complexity and difficulties involved in assessment generally make them more humble and understanding. By inviting the students to share and discuss the challenges, the subject is de-dramatized and the process is made more transparent to the students. It also becomes evident to them that the instructors handle the issue with great awareness, concern and care.

The risk with individual grades, in this course as in many other, is that if the course is elective and demanding, and the final grade is of great importance to the student, he/she might chose a less demanding course instead, in order to gather the same amount of credits and a higher grade for less work. However, we have to rely on the students' own interest in getting the best out of their education rather than optimizing their reward per hour spent. (If we as instructors are not comfortable with the students' attitudes on these matters it might be worth spending some time on that too.)

Efficiency from a Learning Perspective

At the end of the day, the actual learning takes place in the heads of the students. What it all comes down to is that using the teacher time efficiently and maximizing student learning implies activation of the students. As stated by Shuell [4] and quoted by Biggs [5]: "If students are to learn desired outcomes in a reasonably effective manner, then the teacher’s fundamental task is to get students to engage in learning activities that are likely to result in their achieving those outcomes... It is helpful to remember that what the student does is actually more important in determining what is learned than what the teacher does." Obviously it does matter what the teachers do in terms of preparation and sending the right messages to the students but not necessarily in terms of classroom "stage-performance". The interesting thing is that this attitude towards teaching and learning could help the teacher to design a course so that student learning is enhanced without generating more work for the teacher. If an infrastructure is provided by means of an approximate time plan with key deliverables and deadlines, basic equipment and a timely sequence of instructional modules, both for practical and intellectual activities, then the overall management and realization of the project could be almost entirely delegated to the students. This is achieved by making it clear that the responsibility for solving the task lays on them. The work requires efficient use of students' time and other resources, which calls for planning and follow-up. Successful completion of the work requires critical evaluation of ideas and verification of suggested solution methods implying that written and oral presentations, and critical reading and opposition, also come as natural parts of the process.

There are certain activities worth spending time on in order to save time. We use quite a lot of our attention on monitoring the process. We ask for regular (brief, oral) status reports. Every now and then we informally ask students in different roles in the projects how things are progressing, if there are any potential problems or serious conflicts in the group. We ask the project groups for regular time and budget reports, not so much for our own control as for sending the message that we care about how the project spend its resources, and so should they. By monitoring the process carefully we do not feel the need to interfere too often. We are less nervous and can steer the progress of the work by very small means, which also make our interventions less obvious to the students. To our minds a comfortable position is when you like an aircraft pilot have access to all kinds of instrument data and then can ignore 99% of it during 99% of your time. For instance if we receive signals that the project management is not running smoothly we could suggest that the group discusses if it is a good idea to rotate some of the responsibilities in the project. Such suggestions are often enough to initiate positive changes in the project organization without letting the problems dominate the discussions and generate "negative energy" in the group. There are also specific activities in the course intended for deeper reflection on problem and success factors during the work. Such exercises are however better performed in some retrospect rather than in the middle of a potential crisis.

Concluding Remarks

Engineering education as well as higher education in general has historically been managed and taught by experts in the specific areas studied at the institutions. The curriculum has been set based on the experts' collective opinion on what knowledge, methods and skills should be mastered by graduates from a given course or educational program. The content has typically been aligned through inter-institutional comparison and exchange of views, often influenced by input from external stakeholders representing e.g. other institutions, government authorities, industry or other external organizations. Through such processes the content of old established engineering programs has slowly developed and matured into reasonably similar and equivalent educations all over the world. However, during more recent years while new areas of technology have rapidly emerged and existing areas have grown and branched into several different specializations the educational programs have been forced to evolve correspondingly. At times, representatives from rapidly growing areas accuse educational institutions for not updating their curricula rapidly or frequently enough to meet the needs from industry. On the other hand these strongly progressive fields are typically very research intensive, suggesting that what industry really needs is a staff profile that is theoretically stronger rather than updated on the latest trends. This conflict is obviously reflecting aspects that are far more complex and totally beyond the scope of this paper but the paradox illustrates much of the challenges in design of engineering education. The task is to provide industry and society with engineers fit for the job, no matter what 'the job' is as long as it falls under the category *engineering*. There is obviously an infinite number of ways to approach this conflict of interests and we do not claim that we know how to do it. However, it is a fundamental paradox that has effect on many of the priorities and decisions we make when designing a course or a curriculum. Let us elaborate a bit on two extreme standpoints. The more fundamental, theory-preserving one is that a sound and deep knowledge in pure science such as mathematics and physics is what best matches all needs since fundamental theoretical knowledge is applicable in all fields of technology. The latter is apparently true but application of fundamental physical principles on e.g. aeronautics or robotics is quite elaborate and is better done through help of existing experience, theoretical models and methodologies developed over time to form a specialized body of knowledge that eventually has come to constitute a field of technology. The other extreme is to claim that theoretical fundamentals are too far from the field of application to justify their presence in the education and that a thorough theoretical background would only distract the students and reduce the time spent on more readily applicable knowledge. This might be sensible if the aim of the education is only to make the students familiar with existing methodologies and practices but not really to contribute to further development in the field. The question could also be raised whether or not the concept of higher education inherently implies that it should build on previous knowledge of a certain level. Which type of engineers do we want to educate, ones who are able to recite the findings of others or ones who are able to contribute to development of knowledge and theory?

Quality of a course relies on quality in details. As a course manager one should care about the quality at all levels and continuously ask questions like; Is this part of the course relevant? Is students' time used efficiently? Is this guest lecturer providing what the students need? Does the pedagogical value of this activity motivate the work spent? Is student learning in focus now? As our course has evolved we identify that the teacher focus has shifted from details in the project itself towards the details concerned with the learning activities taking place. We clearly distinguish the learning activities from the project goals and continuously communicate the difference to all parties involved. As discussed above, handing the project work over to the students allows them to grow with the responsibility, but further and equally important, it allows the teacher to spend more time on course design for maximized learning.

The final important concluding remark is that looking back at what we have accomplished could simply be summarized in terms that apply to most examples of good management. Make people involved, provide them with adequate resources and support, and nurture the process carefully.

Disclaimer

Engineering education is a sub-class of higher education that is directed towards certain professional abilities brought about through unification of scientific and experiential knowledge. From a science point of view engineering is "applied" while from the perspective of the application it is often considered as being very theoretical. The presented findings and conclusions in this paper are not necessarily restricted to engineering education only but we avoid claiming their validity for higher education in general due to the vast width of such education.

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