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MULTI-PROFESSIONAL PROJECT AS FINAL MASTER PROJECT FOR DESIGNERS

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1. Introduction

The traditional engineering education in universities has focused on teaching the basic sciences of engineering. This, presumably, should make the students able to understand problems and then find the solutions. This may work for problem solving, but in design problem solving is only part of the challenge. Process understanding and methodology knowledge is just as essential for design processes to succeed. Hardly any products today only relate to one profession or one science. Ever more advanced products require ever more scientific knowledge and competence. Together, this means that design projects today need to be integrated, cross-disciplinary and systematic efforts in order to succeed. Understanding of scientific basics is fundamental, but not at all sufficient.
Eder and Hubka [Eder, 2005] list these types of competencies, which design engineers should be trained in during their education:

- Heuristics or practice-related competency
- Branch or subject-related competency
- Methods-related competency
- Systems-related competency
- Personal and social competency
- Socio-economic competency

Of these, only the second and fourth are covered with to any satisfaction in the traditional engineering study.
A thorough model for comprehensive, multi-professional courses in engineering, is the CDIO, as presented by [Crawley, 2007].
If universities concentrate on only basic sciences, all the other areas must be learned on the job or in in-house training in the companies hiring the students after their graduation. This could mean a lot of in-house education, and we know that the acceptance for that in industry has gone down as demands have become tougher [Green, 2006].
Most design educations on master level have a master project during the last year. This may take a full year or less. In our university it takes up all of the last semester and half of the preceding. Typically, the candidate is given a problem to solve. And typically he or she works alone on this, possibly with some cooperation from the company that came up with the assignment. Teachers tend to see this as an extended exam: The student is supposed to use the project to show what he/she has learned during the preceding study. One result of this is that many students have limited learning results from the last year of their education.
In order to make the education better adapted to the reality that will meet students in industry, we need to expand learning to include work methodologies and team work, and make the students able to

handle a typical industrial design situation, where information is sketchy, decisions must be made based on limited information, and where available time and resources do not seem to be adequate.
This paper reports on an effort done at NTNU (The Norwegian University of Science and Technology) to improve the masters project that make up last year of the masters study. It was originally meant for the students of the Mechanical engineering program, but was eventually expanded to go beyond that. The preparation for this effort started in spring 2007, the actual project started in fall 2007, and the paper is based on the status at the end of the spring term 2009, that is after two years.
Ideally, an outside researcher should have followed the project to investigate the working, cooperation and progress, but such resources have not been available. This reporting is therefore by the instigating teacher, possibly being too close to the project. Still, the experiences should be of value to other teachers in the same situation.

2. Approach

We wanted to improve our master study by making our students more adapted to the industrial reality and more able to cope with the conditions offered them in industry. We therefore decided that we would try to do something more out of the master project.
Using almost a year of the study only to evaluate the student, seems excessive. The beneficiary of the grading is ultimately the employer, but there is no indication that these employers would rather have a precise ranking of students than a general expansion of their knowledge and capabilities. We therefore decided that learning should be the focus more than evaluation.
The CDIO approach, as presented by [Crawley, et al., 2007] and [Andersson, et al., 2005], seems to fulfill the requirements for a learning project. We therefore decided to use this as a model.
If we focus on making the master project a learning experience, we may have to compromise when it comes to evaluation and grading. However, grading of design projects has never been an exact science, and making sure the students come out with a more appropriate knowledge base should more than compensate for lack of grading accuracy.
A major problem with typical master projects is that they are simplified. This means that the student get a type of problem which is adapted to what he has learned, and where all "disturbing" elements are removed. This is very different from what he or she will later experience in their work life. In typical design situations, finding out what the essence of the problem is, is often a major part of the work. So we wanted to give students a realistic challenge, where they themselves would have to find out what technologies to apply and what solutions to investigate.
In industry, people are not recommended for having tried, but failed. We therefore wanted to have a project where not reaching the goal was not acceptable. Students have a tendency to reduce the challenge by saying that "I didn't reach the goal, but at least I have shown that I know how to work in such projects", and this we would not have here.
If anything characterizes modern design projects, it's the multidisciplinary project team. All products are "multidisciplinary" – that is requires knowledge and solutions from more than one engineering profession or science – to some extent, and many more and more so. The "lone genius", who sits by himself and solves problems within his specialty, is not a common sight.
According to Duncan & al [2006], the term multiprofessional in the medical realm reflects the many professions needed to work together to fulfill the given task, as opposed to interprofessional, which simply means that people from different professions work together. They use "profession" to denote doctors of various specialization, nurses and other medical functions. Although it can be argued that all engineers are of the same profession, we find that in practice the multiprofessional team in medicine and the multidisciplinary development teams in engineering are analogous. For us, the multiprofessional team means that engineers of different disciplines have to learn how to communicate and cooperate, but it also means that non-engineering disciplines must be included. Marketing, finance, customer psychology and many more non-engineering disciplines are relevant. But even the integration of engineering disciplines is a challenging task, since terminology, scientific traditions etc are very different. From a mechanical engineering perspective, the integration with electronics, computer science and cybernetics seems to be extremely important, but is non-existent in education. This very much reflects the multiprofessional team as defined by Duncan & al.

Why this is important is not difficult to see: Industrial projects are multiprofessional, and since working in such teams is not trivial, educational experience with it would be a key to efficient and productive projects [Fain, et al., 2008].
Any realistic project requires lots of resources. Usually, they are not readily available, and must be found. Economy is one such resource, and in our case, the project must have sponsors, since university funding is minimal. Finding good sponsors, making the right contract with them, and making sure they are satisfied with the return on their investment is a vital part of such a project.
There is no technical aspect of this, but still it is very close to the reality that the students will meet in their work after their studies are finished. Designers in industry must always "sell" their ideas to those who control the resources – management, financial functions, etc.
Resources necessary to realize a design project like the one we foresee, include:

- Money
- Scientific competence
- Materials and components
- Workshop facilities

One important aspect of such a learning master project, is the teachers role. Whereas in an ordinary one-student-one-teacher project he will be the student's main discussion partner, this will not be the role here. Much more, he will supervise the project's progress and facilitate student activities.
For the students, the most important discussion partners will be the other members of their own team. Since these are from different science areas, they will often be able to answer many more questions that the teacher can.
The teacher's role, will be to watch over the project progress, and to guide the team in the right direction. One example of such guidance, could be that if the team opts for a very promising solution with high uncertainty, the teacher should urge them to develop a simpler, more certain backup solution in addition.
If students from multiple departments are involved, a teacher from each of the departments should also be involved. As an added benefit, one will then get a "teacher team" that would represent very diverse competence and knowledge, and which could be interesting as discussion partners also between themselves.
When the experiment started out, we wanted to see if these results could be achieved:

- students who reported they had learned much during the year
- industry interest in the project
- publicity for the study program

The success of the project would then be judged by the degree these results were achieved.

3. Case study – experiment conducted

We wanted to find a project, with a number of characteristics:

- Completeness of development process – that is going from a goal formulation to physical results [Green, 2006]
- A measureable goal
- Need to integrate multiple disciplines of engineering, that is multiprofessionality
- Potential for publicity

And it should train as many as possible of Eder and Hubka's competencies (see ch 1).
The first three on the list, coincide with CDIO [Crawley, et al., 2007].
In addition, it was desirable that the project was within one of the two product areas which our department specializes in: Transportation products or equipment for oil production and processing.
In transportation there are some interesting competitions for student groups. Foremost among these are Shell Eco-marathon, Formula Student and Formula Zero, plus some solar energy vehicle competitions.
For us, one project possibility stood out, namely the Shell Eco-marathon [Shell Webpage]. This is a well-established competition with environmental focus and with participation from the most respected universities in Europe and beyond. Norwegian participation had been limited to two not very successful entries by the Østfold University College industrial design education.

Shell Eco-marathon is a competition based on some simple principles. Student teams should design, build and race a car with fuel economy in focus. The energy consumption during the race is measured, and for each car, the range it would go on the energy equivalent of a liter of gasoline is calculated. Whoever gets the highest number wins. This means that if a car is based on solar power, which is one of the legal possibilities, one does not measure how far it goes in a given time, but how much energy it has used traveling the given distance. Thus, a larger solar panel is not a way to improve the outcome.
The cars themselves must be within a set of specifications set up by Shell. These are controlled and are not negotiable.
There are two main classes of vehicles in the competition: Prototype and Urban concept. The prototype class is the original one (going back to the start in 1983), with very open specifications and large possibilities for extremely low consumption. The vehicles are mostly based on bicycle technology, are very small and extremely light. Most have only 3 wheels.
The urban concept class was instigated early in this century in order to promote more realistic and car-like vehicles. In this class, 4 wheels of given dimension is a requirement, as is a closed body with windscreens and door, a minimum interior height, minimum body dimensions and a requirement on roll-over roof strength. It must also have functioning lights and other car-like features.
Each car is given three chances to race, and the best result counts. To get a result, the car must finish a distance of 23km with a minimum average speed of 25 km/h, and with 3 required stops.

3.1 Establishing the team

Finding mechanical engineering students was not biggest challenge, possibly because the department was very eager and did PR for the project.
Finding students from other departments was more of a challenge. The driving force was not present in these departments to the same degree. However, we eventually found students within power electronics, fluid dynamics, industrial design and project management. In the second year we also included a chemistry student and two from cybernetics.

3.2 Getting the resources

The resource issue is a big one in such a project. Not only are various competences needed, but resources of many kinds are essential. Some of these we had available, like a nice machine workshop with machines and general tools.
Financial resources were quite another thing. The university has very limited possibility of funding such a project. The first student group made a budget of roughly 1MNOK (~120k€), and more than 90% had to be found from outside sources. Finding sponsors was therefore one of the most important tasks for the project group. We would have to find business sponsors who would like to have their name associated with our project. As it turned out, a major hotel chain, which is very high profile in environmental issues, wanted to support us, and they gave us the amount we needed. Smaller sponsors were also found, most of those provided materials or services rather than cash support.
Materials and components were also an issue. To get an edge on the competition, we decided that our car would have a carbon fiber monocoque – the competition all have framebased designs. This meant high costs, not only because the pre-preg carbon fiber is extremely costly, but it requires a high quality molding process and a high quality form. This had probably not been feasible had we not found a partner – a sponsor – who let us manufacture the mold at their premises, let us use their autoclave, and provided valuable assistance in the entire process.
Many of the components were small and could be bought off the shelf, but two important components were in a different league: The fuel cell and the electromotor. In the first year, we had too little knowledge to try to build anything ourselves, so we ended up with the same off-the-shelf fuel cell solution that our main competitors used. And as for electromotor, we chose a model airplane motor that was much too high-revving, but otherwise had good specifications. For the second year, we were more courageous. We now had a chemistry student and a cybernetics student to work on the fuel cell, and a power electronics student with expertise on motors to work on the motor. We therefore chose to purchase just a fuel cell stack, with no control system, no feeding, no cooling etc, and build our own

system out of it, and to design our own slow-revving electromotor, based on an existing one made by a partner company. Both of these components were major contributors to our success in the race.

3.3 Supervision

Two areas will be highlighted that both concern the teacher's situation: Grading and supervision.
The issue of grading has been a difficult one. Maybe the most difficult of all, seen from a teacher perspective.
We soon decided on common grades for the team, since it would be very difficult to identify individual results in such a project, and because if each should be evaluated on his scientific contribution, nobody would do the tedious, but necessary, sponsor work and press relations work, and we would risk that students would focus on their limited area, and not be willing to help the others when necessary. But since we have students from more than one department, we also have the issue of different standards in the departments, and this has led to one department giving better grades to their students than what the rest of the team got. This, not surprisingly, was not very popular, but was accepted because the students in question had contributed a lot.
Since the final project counts more than other courses, many students are skeptical to being dependent on others' effort and performance for this grade. Some feel that they can do better on their own than the team. This is an issue when it comes to recruiting students to the team.
In our tradition, the grade is based mainly on the report from the project. There is no grading on intermediate stages, but the teacher would, of course, include an evaluation of how the student has worked during the project in his assessment. We also bring in an external sensor to set the grade together with the teacher, and this sensor is only involved after that project is finished and therefore bases his assessment solely on the report.
Grading based on report alone would in this case be impossible. If we said from the start that the project would be graded based on the report, the project could never go through, because so many crucial elements would be ignored. What would come out would be a, probably uninteresting, report on what could and should be done if one was to go through with such a project. So, although the report was still important, we had to include many other issues in the evaluation.

4. Results

4.1 Academic results

What were the academic results from this project? That is not easy to pinpoint. Each student had his/her own results, but the main academic result is that each student has seen his own knowledge and competence go into a practical project, and has seen that without the knowledge and competence of each single one of them, there would not be a result like the one they achieved. Another effect, which is important but often overlooked in universities, is the learning across curricular boundaries that happened in the project. For the first time, we saw cybernetics students interested to learn more about design methodology as it is taught to mechanical engineering students. We also saw electromotor experts working with mechanics students to dimension parts of the motor properly, and mechanical students with a whole new understanding of cybernetics, etc, etc. This is the second important academic result from the project. In our opinion, the students who had been through this project should be much more attractive to industry than those who hadn't.
All in all, we think the students have experienced progress in all of Eder and Hubka's compentency areas.
We do, however, not have data to verify this claim, so it is the subjective impression of those involved.

4.2 Project results

One of the findings of the project is that there are a number of areas and challenges that are crucial to such a project that are not of academic nature. First and foremost of these, is funding: Finding sufficient funding for such a project is critical. It requires a level of funding that goes far beyond the possibilities of most universities.
We found that sponsors were essential to a successful project.

Our first year team ended up with a very good deal with a hotel chain – Choice Hotels Scandinavia – whose owner is known for his dedication to all things green, and also for his car interest. This sponsor also set us in contact with an environmental certification institution.
The second year, we found an even better sponsor. This was DNV, a company famous for certifying ships, but also big on ISO9000 and ISO14000 certification, the latter setting standards for environmental issues. The company is one of the larger employers of former students from our program, and therefore was interested both in the technical aspects of the car, as well as in the educational outcome of the project. They eventually hired one of the students on the team.
If there are any components to the car that are more important than the others, it is these three: the body (because it represents a large amount of weight and because it gives the car certain critical properties, like aerodynamics and stability), the electromotor (because it can decide whether or not gearing is necessary, and because it determines a large part of the efficiency of the car) and the fuel cell (because it decides how efficiently the hydrogen is transformed to electricity).
The first year group emphasized the body, and found a sponsor with lots of expertise in carbon fiber fabrication (Kongsberg Defense and Aerospace), and which also has excellent facilities for making both the molds for such a large component and for making the actual body. The result was amazing: Whereas no competitor's car weighed less than 94kg, ours weighed 69! A major part of this was the use of a monocoque structure instead of a body-on-frame. The other two critical components did not get the same attention, and were off-the-shelf products: A model airplane electromotor and a Ballard Nexa 1200 fuel cell.
The second year group early on decided to keep the car body as a basis for their development, mainly because it was seen as very successful. They did, however, get it into the wind tunnel and found out that it was not as aerodynamically efficient as they thought. They therefore began a process of finding ways to improve on the aerodynamics without ruining the good properties of the body. They ended up with three main alterations to the body: The rear end was lengthened by 60 cm to get a more laminar air flow, a duct under the car was covered, and the mirrors were moved from outside the car to inside.
But the main focus was on the other two components. Instead of the off-the-shelf fuel cell, a Ballard stack was bought, and the team made the system themselves. This means that they designed the entire control system for the stack, including feeding, and also the cooling system. The result was found to be much more efficient electricity generation, and a system we had much more control over thereby allowing testing of different driving strategies. There was no sponsor with competence on this. The first year electromotor was a high-speed unit, and it required a 1:10 gearing in order to work with the speed range of the car. A gearless solution based on a low-speed motor was identified as a potential source of improvement, and a sponsor was found with expertise on such motors (Smart Motor). They had in their portfolio a motor for small, unmanned submarines with interesting specifications. In the end, the students designed their own motor on the basis of this, with considerable expertise coming from the sponsor. The result was a motor which did not require gearing, but was much bigger and heavier than the previous year's motor. Calculations showed, however, that this was a much better solution.
We – the teachers – had told the students that starting in the race was a demand, and that anything but a valid result would be considered a disappointment. This was contrary to some observers who said that "whether they finish the car or not, they have learned a lot and can write a good report". In an industrial project, you are seldom recommended for having tried, you must finish, and we wanted the students to experience that kind of pressure.
The first year, we hoped to have two weeks of test time after the car was finished and before the race, but that never happened. The students' ambitions grew, and they filled those two weeks with additions and improvements, so that the car was never really tested before the final event. Therefore, we brought a rather complete, small workshop, so that not some minor thing should break and stop us. This happened in our first attempt, when an underdimensioned fuse blew, but the next two heats were successful, and yielded a counting result of 729km/l. This gave us the silver medal, behind a Dutch team that had won for 4 consecutive years.
The second year, we had higher ambitions, and said that 1000km/l must be the goal. With the new motor, the new fuel cell, the improved aerodynamics and all the new computer support being available

to the driver, beating last year's result was expected. Also this year we experienced problems during the first heats and had to do on the spot improvements, but then in the 3rd attempt: Success! 1246km/l was a new record for the urban concept class, and 50% better than the silver medal winner! Figure 1. shows the team and the car after the victory.

Figure 1. The car and the team

4.3 Team results

The teams – both the first year team and the second year team – were thrown into deep water. They had never before experienced such a serious project with such high demands, so large and diverse a team, and no tasks defined, only goals.

The first year team functioned well. They reached their goals and they were good at involving the supervisor group and the sponsors. They had a very flat structure, where some strong personalities acted more as a team leader than the appointed leader. This could be due to the fact the appointed leader was appointed based on his curriculum – project management – rather than his personality. Documentation was somewhat haphazard; the team obviously did not see the value of good, structured files, and they relied heavily on the collective memory of the team. And that worked well for them, but made things more difficult for the team taking over after them. Their effort on the PR side was recommendable, as they had chosen a responsible for this activity that obviously liked talking to journalist and appearing in newspapers as well as radio and TV. Norway's leading TV channel followed the project from the onset, and even sent a team to cover the race in France. What resulted was a long feature on the most popular TV news show on the most popular hour of the week. This was excellent PR for our university and our education program.

The second year team organized themselves differently, more democratic and with higher involvement. They were very good at subdividing the project into manageable tasks for each student to fulfill. They used their allocated project area to good effect, and had a less formalized work style. This worked well for them, but meant less involvement of both the supervisor group and sponsors and others. Report writing was probably the team's biggest shortcoming. The resulting reports were neither very well written nor going into sufficient depth on the most critical issues. All in all, reporting When it came to PR, it was a problem for them that last year's team had gotten so much publicity; the TV station was, for instance, not interested in doing a new feature so soon after the last one.

The multiprofessional nature were a primary characteristic of the teams. In both cases we saw that this resultet in more interested and more learning students. We do not, however, know how much of that was due to the students in question and how much was due to multiprofessionalism as such. Again, this remains subjective interpretations of the workings and results of the groups.

4.4 Industrial results

Can we talk about industrial results? This was not an industrial project, so there were, of course, no direct industrial results. But one of the overall goals of the experiment was to provide the industry with candidates better suited to the work situations they would meet there. Was that successful? We cannot judge the result after so short time, but early indications are that it was.

4.5 Success criteria

Our three criteria for success in the experiment, were:

- students who reported they had learned much during the year
- industry interest in the project
- publicity for the study program

None of these have been measured quantitatively. We have only talked to students and industry partners. The first criterion seems to be fulfilled, with statements like “I have learned more this year than in any preceeding year.” All students in the two years have reported high degree of learning during the project.

Industry interest in the project and in the students: Companies with close ties and much knowledge about the project have been overwhelmingly positive. Companies without such ties vary in their attitude.

The publicity effect has been larger than expected. The TV program about the project and the printed press coverage are often referred to by freshmen when explaining why they wanted to join the study program. Also in industry is this often mentioned when our study program is discussed.

5. Conclusions

We have found this type of masters project to give us new possibilities in training engineering students for the industrial reality. As such, it has been an overwhelming success. All students involved have expressed their enthusiasm for this way of working, and the sponsors have all been convinced that this will give them better candidates. Certain issues have not been satisfactorily resolved, such as grading, an issue which needs further development. One possibility is to involve external, industrial evaluators throughout the project. Also, future projects must add new challenges, so that new student groups will not only walk in the footsteps of their predecessors.

So far, this project has been limited to 5-6 of our students per year, roughly 15% of our masters candidates, and based on the experiences so far, we should have other parallel projects with similar characteristics. Preferably, this should be within the other product focus area of the department, equipment for oil production. Later on we foresee an expansion into other areas as well.

But we still see a need for single-student projects of a more traditional character. Some students express a strong opinion against team projects, and such students would probably not contribute productively if forced into a team.

An additional challenge will then be to find ways of evaluating those two types of projects in a way that is fair to all. For this, we so far have no solution.

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