INTEGRATING CDIO EXPERIENCES INTO A NEW PROGRAM ENVIRONMENT

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Abstract
This paper provides a creative approach on how to implement CDIO-techniques into a Engineering Physics program. A comparison is made between the Vehicle Engineering program and the Engineering Physics program at the Royal Institute of Technology (KTH), in order to establish what the grounds and potentials for implementing CDIO into a new program environment are. The Engineering Physics program is examined not only though the comparison but also through an indicatory survey performed with students, instructors and representatives from the industry. This is done in order to map the perceived nature of the program. Furthermore, these potentials are explored from the view of the Engineering Physics program at KTH, and implementation strategies are suggested and elaborated in accordance with derived results and indicators, using modelling and simulation as a ground for an abstract product orientation.

Keywords
Engineering physics, modelling, simulation, system perspective

Introduction
This paper poses the question of what potential CDIO holds for other educational programs than the classical engineering educations, in particular the Engineering Physics program at the Royal Institute of Technology in Sweden, and how this can be optimally explored. The paper is structured so as to first analyse the landscape in terms of educational structures and surrounding situation in part I, then pose a core question which can be treated and answered in the following parts. Part II mainly consists of a set of survey interviews and the following analysis. Finally, part III presents suggested strategies for acting upon the accumulated problems and use the acquired information in a efficient way.

Part I – Landscape Analysis

Engineers of the 21st Century

The categorisation of engineers and engineering disciplines is a hard task and no doubt one that requires close study of what role the 21st century engineers play in developing society and technology. Intuitively one might want to use a regular pie chart to give each engineering discipline its rightful piece, but upon pursuing this division it will soon become apparent that this is an impossible task.

There are so many different kinds of engineering disciplines and levels of focus for engineers of today, that to categorise them one would need to refer to a model of three dimensions, rather than one of two dimensions and simple division. Imagine instead a cylinder model divided vertically into different layers, which in turn are divided into separate pieces, as shown in Figure 1. Adding this new dimension allows us to categorise the level of detail in correlation to the field of study, meaning that a higher level pie chart would symbolise a more abstract approach to the subject. This might not seem that revolutionary, but suppose also that the different layers are interconnected so that they only make sense as a whole. That would be one rough way of trying to portrait the diversity of engineering disciplines and how they are tightly integrated into our modern communication- and information society. This is not in any way something to be shunned, as it defines a proud history and a strong development of engineering as a vital part of the civilised world. On the contrary, as we study the education of engineers it is important to keep this diversity in mind and take into account the strengths it can contribute to the finalised product; the next generation of engineers.

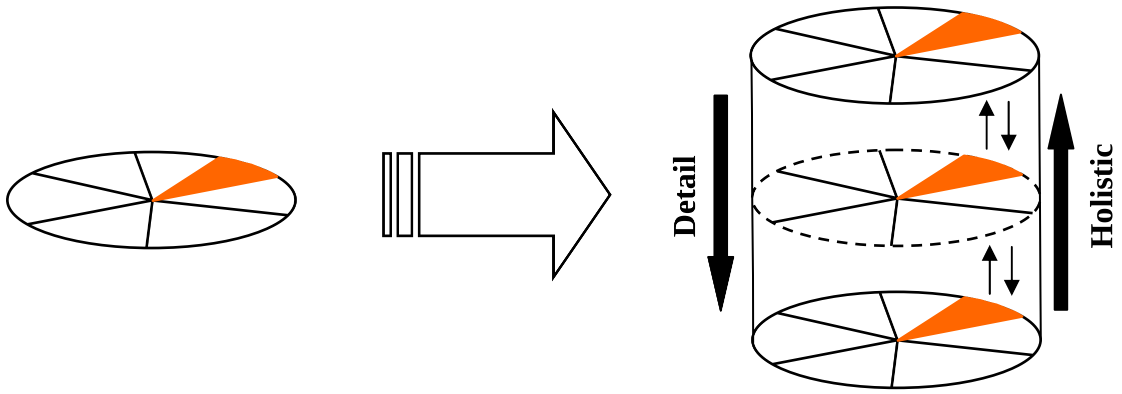

Figure 1. Moving from a 2-dimensional to a 3-dimensional categorization model for engineering disciplines.

This paper is not dedicated to exploring the categorisation of engineering disciplines, but it is all the same important to keep the diversity of the engineer's role in mind when we design and redesign engineering education to adopt it to the needs of the industry and of society as a whole. The CDIO-initiative clearly portraits the need for engineers who can actually build things with their engineering skills, but it just as clearly points to the need of diversity within engineers as a group. It is, in our view, very important to recognise and acknowledge the need for engineers who build models, based on real world phenomena and products, as just as great as that for actual construction engineers. A simple example could constitute the designing and building of an aircraft, in which case it would be crucial to include a system engineer to create and model an overview of the entire construction as well as a construction engineer to design the best possible wing profile from the given constraints. It is important for every engineer to see both these perspectives during their education.

Vehicle Engineering Program

The Vehicle Engineering Program at the Royal Institute of Technology was one of the first programs that adopted the CDIO-model for engineering education. This model has since been adopted as a role model for engineering education by the Swedish Agency for Higher Education (HSV). Consequently, the Vehicle Engineering program was given very positive reviews by HSV in a recent evaluation of all engineering educations in Sweden.

The program consists of three significant parts: Mathematics dominate the first part, together with core courses in the technology specific to the program. The second part consists of basic technical-scientific courses that offer the students a broad basic knowledge in technology and science. Finally, the third part constitutes the specialisation within the program and includes both courses and an M.Sc final degree project with written thesis.

The specialisations constitute blocks of their own with required as well as optional courses. Thus, the student gets to influence, on a larger scale, what area he or she would like to major in, as well as, on a smaller scale, which courses will be included in his or her diploma.

In the Vehicle Engineering program, the teaching of engineering theory is frequently exemplified by applications from the automotive, truck, aircraft or marine industry, and the understanding of practical applications of course makes the student's learning of the fundamentals much easier.

During the first 3 years the students follow a given course plan, which is followed by an individually chosen specialisation from one of several fields. The entire structure is displayed in Figure 2.

MSc in Vehicle Engineering

Year 1

Mathematics	Physics	Vehicle Engineering Courses	Computer Science

Year 2

Mathematics	Applied Mechanics

Year 3

Electrical and Mechanical Courses	In-depth profile

Year 4-5

Specialisation

MSc Final Degree Project

Compulsory Courses for all students - year 1-3

Year 1:
Numerical Methods and Basic Programming
Perspectives on Vehicle Engineering
Physics
Analytical Methods and Linear Algebra
Mechanics, basic course

Year 2:
Sound and Vibrations
Solid Mechanics
Product Development
Differential Equations
Mechanics
Thermodynamics for vehicle engineering
Fluid Mechanics

Year 3:
Automatic Control
Signals and Mechanical Systems
FEM for Engineering Applications
Electrical Engineering
Mathematical Statistics
Optimization theory

Specialisations:
Vehicle Technology
Solid Mechanics
Sound, Vibrations and Signals
Lightweight Constructions
Mechanics
Systems Engineering
Aeronautics
Naval Architecture

Figure 2. Educational structure of the Vehicle Engineering program.

Engineering Physics Program

The Engineering Physics program at the Royal Institute of Technology belongs to the same organisational department of KTH as the Vehicle Engineering program, but apart from this the two educations do not share much when it comes to organisational structure, although the two disciplines share some contents.

The Engineering Physics program has taken upon itself to educate engineers in the area of scientific engineering, in an attempt to create engineers with a broad perspective and a good overall knowledge. The program consists of two main parts. The first part constitutes the greater part of the first three years and consists of a considerable amount of fundamental mathematics and fundamentals from several fields within physics and mechanics. The second part is made up by the student's specialisation and constitutes the remainder of the educational program. The students primarily choose specialisations in the areas of physics, mathematics or mechanics, and within these three areas there are several subcategories spanning from theoretical physics to solid state physics and financial mathematics. The educational structure is displayed in Figure 3.

Unlike the Vehicle Engineering program, the specialisations are not specific blocks and each student creates his or her own field of specialisation by choosing course by course. This procedure is regulated by the instructors who are responsible for each specialisation, who declare what courses must be included in order to be allowed to do a master thesis within that field, but these regulations are not as strong as those of the Vehicle Engineering program. To support the process each specialisation is described in terms of goals and recommended courses, but very few are labelled compulsory. To ensure the quality of graduating students there are regulations for how many academic credits the students must achieve at a minimum on a certain level of sophistication and depth, but apart from that the students are free to design their own area of specialisation.

Engineers from the Engineering Physics program tend to move to a great diversity of other areas when they have graduated. A preliminary study made by students at the program suggests that as many as 30% of the students strive to get an academic career and go into research, while the remaining 70% are divided amongst areas like investment banking, management- and technology consulting, programming and software development, automation, energy consulting, space and aeronautics, R&D at technological- and medical companies and heavy industries.

MSc in Engineering Physics

Year 1

Mathematics	Physics	Computer Science	Mechanics

Year 2

Mathematics	Engineering Subjects	Physics	Computer Science	Mechanics

Year 3

Computer Science	Engineering Subjects	Physics	Specialisation and Elective Courses

Year 4-4,5

Specialisation and Elective Courses
MSc Final Degree Project

Compulsory Courses for all students - year 1-3
Year 1:
Program Construction
Physics, Basic Course
Calculus
Linear Algebra
Mechanics, Basic Course
Year 2:
Electromagnetic Theory
Numerical Methods
Solid Mechanics
Modern Physics
Mathematical Methods in Physics
Complex Analysis
Differential Equations and Transforms
Mechanics
Year 3:
Solid State Physics
Fundamentals of Computer Science
Automatic Control
Statistical Physics
Probability Theory and Statistics

Specialisations:
Physics:
Atomic and Subatomic Physics
Biological Physics and Medical Engineering
Condensed Matter Physics
Laser Physics and Quantum Optics
Mathematical Physics
Nuclear Energy Engineering
Material Physics
Microelectronics

Mathematics/Computer Science:
Discrete Mathematics and Computer Science
Mathematics
Optimisation and Systems Theory
Mathematical Statistics and Financial Mathematics
Scientific Computing and Computational Mathematics

Mechanics:
Solid Mechanics
Sound, Vibrations and Signals
Theoretical and Applied Mechanics
Fluid Mechanics

Figure 3. Educational structure of the Engineering Physics program.

Comparison from CDIO Point of View

Comparing Vehicle Engineering to Engineering Physics a few differences become immediately apparent. For one thing, the Vehicle Engineering program is structured all the way through, while the Engineering Physics program constitutes a structured first fundamental part followed by an individually constructed specialisation. This difference brings about both pros and cons on behalf of the Engineering Physics program. For example, it would be hard to create any deeper connection between several of the courses included in the specialisations, since there is no saying exactly which courses any student will take or in what order they will be taken (apart from some recommendations due to prerequisites). On the other hand, the students make conscious decisions about how to further their knowledge within their field of specialisation. This open structure demands much from the students as well as the system, but it also allows for a more creative take on education and it provokes the students to ask themselves what they want to become good at, and why. The Vehicle Engineering program can in contrast to this offer its students a clearly structured overview and introduction to each and every of its specialisation fields, and due to a dynamical approach to teaching and learning this structure also allows for the students to become really familiar with the field they want to educate themselves within and hopefully continue to work within. It is important to notice that the students at the Vehicle Engineering program also choose a fraction of their courses freely, albeit not as a large a fraction as for the Engineering Physics students.

Furthermore, the Vehicle Engineering program allows for a more hands-on approach to the learning material, whereas the core of the Engineering Physics program per say puts it further away from the actual construction and manipulation of any one specific area of technology. In this sense, the name of the educational program can be misleading, since it is not the sole goal of the program to educate physicists, but rather Engineering mathematicians with a good understanding of physics. Although the Engineering Physics program lacks a specific target sector within industry and/or research this does not automatically mean that the program lacks structure, but rather that defining product and target area might require another element to the equation before we can make use of the tools developed to examine other engineering educations.

The aim of the Engineering Physics program is to educate engineers who can work with high confidence from a system perspective. This can be achieved by providing the students with many different and correlated examples of mathematical and physical problem models and their solutions. This combination of fields results in a strengthened system perspective on a general basis , but with a lack of depth in any specific field of study as a result. Its important to differentiate between specific depth and general depth, the latter of which the program has reasonable amounts. This is partly compensated by the specialisations where the student freely specialises in some aspect of some field, and it is both interesting and important to take into consideration that several students from the Engineering Physics program have done their specialisations within the framework of other educational program's areas of specialisation, where they have been successful in adapting and following the courses with good results.

The success of the students from the Engineering Physics program is not only due to the program itself, but also to the fact that the program has a reputation of being very demanding, and most students who enrol are very ambitious. This causes us to pose the question of how we can measure the relative improvement of the individual student to ensure the quality of the program as well as that of the graduating students.

The Engineering Physics program has received critique from the National Board for Higher Education (HSV) for not targeting a specific enough sector within the industry for their engineers, a critique that clearly displays some of the problems associated with the attempts to work with such a wide educational spectrum in one single program. It is intuitively obvious that broadening the fundamental educational structure will in some sense lead to degradation in depth in terms of specific industrial related applications. With this said, the students who graduate from the Engineering Physics program are highly appreciated within the sectors where they continue their careers. This indicates that the educations is not of poor quality, nor too diffuse to create qualitative engineers, but it also indicates that the present view of the engineer might not suffice for categorization anymore.

The core of the Engineering Physics program is mathematics and mathematical modelling, and this allows for a broader perspective on related academic areas. Indeed, there is no single target sector for an engineer with a core education of this sort, but on the other hand every sector has the need for competence of this sort. This returns us again to the problem of defining the engineer's role. The CDIO-initiative is an important contribution to this process of definition, and it is our hope and goal to define and construct a CDIO-based program with the goal of educating future engineers in the subjects of scientific engineering.

Once the goals of the program have been examined, it is important to look at the methods used to achieve these goals. A study performed on the students of the Vehicle Engineering program, during the early stages of the CDIO implementation, showed that most students were good at solving well prepared mathematical problems, while they were ill equipped to pose problems based on general information, and relate problems to the mathematical tool box they had been educated to use. In the light of such results it is evident that it is important to question not only what subjects are taught but also how, why and with what goal they are taught. There is no reason to believe that the students at the Engineering Physics program would perform significantly better at a similar test (one is being planned for this coming fall), and it is evident from a brief overview of course curricula that most examinations today are performed by written exams with well prepared analytical problems.

Defining the Problem

The main problem considered here within is to construct a solid foundation with maintained spread between the different engineering disciplines included in the Engineering Physics program today, but with a clearer integration and correlation between disciplines due to the implementation of the second and the fourth chapters of the CDIO-syllabus. It is our belief that the first and the third chapters of the syllabus can be just as easily applicable to Engineering Physics as to any other educational program, and therefore these chapters will not be thoroughly handled here.

The goal is not to reform the program in accordance to any other program, but to unify the goals of creating a unique educational program and a well developed CDIO-program. Therefore the CDIO-syllabus is used to reconstruct the program so that it integrates the knowledge form different fields without loosing the core or goal of the original program. We aim to find, among other things, a thread of stringency throughout the education, in order to create a web of interconnections within the wide span of subjects.

With this goal we must now define the problem we need to solve to achieve it. First and foremost, this is an organisational problem, in which we need to find a rigorous fundament for the educational program which students, instructors and future employers can agree upon and understand the consistency of. Secondly, we must work to find the connections in between different courses and subjects which are today left to each student to find and understand. This requires us to look at the order in which subjects are taught and how they can relate without loosing their respective focus. With respect to the instructor's work load it is also important to make the best use of their competence and time based on their field of research and their personal specialisations. We will return to this specific problem later.

It is important to differentiate between two possible approaches on how to implement CDIO into the educational structure of an Engineering Physics program. The first would be to focus on physics as the core subject in order to define and highlight a specific product or set of products used in this field, and to relate the CDIO-syllabus to relate to this product or these products. This would allow for stringency and a sector orientation for the program as well as for a concretisation of the subjects taught. A possible take on this would be to introduce the students to projects within biological- and optical physics, or perhaps condensed matter physics. This perspective, and this approach, would in our opinion require little specific adoption work extraordinary to this program compared to any other engineering program. Unfortunately, one might say, this approach does not encapsulate the impression and body of the Engineering Physics program we are working with. The students at the program as well as presumptive students verify that the essence of the program is not restricted to a specific concrete product of physics alone. Therefore, we find this first approach both potentially harmful and uncorrelated to our view of the program, why we have chosen not to follow it. Instead, we are focused on formulating primarily what makes the program good today, and, upon understanding this better, secondly what we could do from a CDIO point of view to improve it and make it even better.

Adding all of the above together, we feel confident that introducing CDIO into Engineering Physics is far from impossible, even though it will require a thoughtful approach in order to avoid reforming the original goal and the spirit of the program. Our hope is that this process will not only result in improvements on the Engineering Physics program, but also that it will generate a furthered knowledge on the role that CDIO plays in an engineering education.

Recognising the Motivation

It is very important not to focus only on the program as a set of courses when reforming and evolving the educational structure, but to also recognise the people involved in the building, working and quality control of the program. Bearing this in mind, we wish to address the question of motivation from two different angles. Firstly, there is the issue of how to summarise the core goals of the program and how to present them in such a way that misunderstandings or wrongful interpretations are avoided. Secondly, it must be taken into to serious consideration how to motivate each part, such as academic divisions, instructors, students and the industry, to commit to and see their own benefits in the formulation of the program.

Based on our view and experience of the Engineering Physics program and comments included in the research interviews we conducted (see Part II), we have decided to pose as the summarising aim of the program to focus on mathematical and physical modelling and simulation, a statement that includes not only the great variety of subjects included in the education, but also emphasises the very strengths of that variety.

The craft of creating and using mathematical models requires not only a good knowledge in problem solving, but also a good understanding of what it takes to pose a good problem, to formulate it as a treatable and testable question. This approach takes full use of the strengths in theoretical understanding which characterises the program today, at the same time as it confronts the need for a wider perspective on how to use that theoretical knowledge. This opens up for an effective introduction of the CDIO-syllabus to respond to that part of mathematical modelling which is not today included in the program structure, without risking the loss of any elements which constitute the strengths of the structure today.

As mentioned briefly above, an Engineering education like the Engineering Physics program is not only constructed by the course plan defining it, but also by its students, its instructors, and the academic divisions it is connected to. Therefore, it is important to take into consideration how each of these groups look upon the program and what part they play in making it a successful education. The Royal Institute of Technology works in close cooperation with the student unions at each program to create a feedback system in which the students can review the courses they take and the instructors can review the courses they give. This machinery is an important part of evolving the program structure on a single-course-level, and it indicated the need for both students and instructors to feel that they have an active role to play in the educational process they are involved in. One question we have posed to ourselves is how we can best create a strong feeling of unity among the different academic divisions and instructors. It is not that instructor distance themselves from one another; the problem is that they do not relate actively to each others' courses and their contents. Faculty, not infrequently, overestimate not only the practical skills and knowledge of the students, but also the connections made between courses. In some sense, the interconnection between courses and the connection to practical knowledge is in many cases left to the students alone today, and that is a major weakness within the program.

We believe that to change an educational program, each instructor must see his or her benefits in terms of how their subjects and courses are affected from the actual change, or else the change will only be perceived as a bureaucratic document which is best left unread. Also, the change can reach far better conclusions if one takes heed to all parts affected. To act on this notion, we have conducted a small indicatory set of research interviews, where students, instructors and representatives from the industry have had their saying on how they perceive the program, its strengths, weaknesses and potential changes. Also, during the past years, we have seen a few examples of how instructors have taken to their own measures to increase the correlation between their respective courses. For example, this year the courses *Mathematical Methods in Physics* and *Numerical Methods* made a joint venture to allow the students to solve physical problems with numerical methods. This example clearly portraits a situation, which mediates a type of knowledge that hitherto has been left for the students to realise or conceive on their own. Although implementing CDIO into the program is a question of far more than connecting two separate courses, it can only be strengthened by the initiative of motivated instructors concerned with how to best contribute to the education of even more competent engineers.

As for the students, there is one thing that is vital to remember: If implementing CDIO becomes too complicated, one might find oneself in a corner where one is needed to teach the students what CDIO is in order for them to be educated in a CDIO-oriented program. This risk is, to our belief, greater for a program such as Engineering Physics, since the products defined to be handled in the program are mostly abstract ones. This is not to say that we should not educate the students in the structure of their education, but if the structure becomes an education in itself we know that we have failed. Therefore we must be conscious of what intuitive perception the program gives, and although that may be diffuse today, it is vital that it does not become even less understandable. In fact, one of the many positive effects of introducing CDIO should be to clarify the structure and progression occurring during the educational process. It is also not only possible, but actually advantageous, to use the students to assess the educational structure and to improve it. This can also, and should also, be said for future employers, who today have very little say in what is to be expected from the students. This is in itself another question which we urge for the further investigation of, but which we can not fully explore here.

Formulating the Question

To summarise the discussion above, we strive to pose a question which we can then proceed to answer. Our question adds up to be the following:

How can we create a stringent and self consistent Engineering Physics program, with the goal of teaching the students to create mathematical models of physical phenomena, using CDIO as a pedagogical tool?

Following this main question is off course many other questions, but these can be handled as they arise. Now it remains for us to handle the question we have posed.

Part II – Analysing the Problem

In order to overlook what perception the people involved with the Engineering Physics program have of the nature and objectives of the program, we have conducted a set of indicatory interviews. This test has only included a small portion of the students, instructors/researcher and representatives from the industry, and following this it is our ambition to continue with a larger and more detailed survey, in which we can follow up the indications we got from this survey.

Survey Interviews

We have conducted three different types of interviews; with students, instructors/researchers and representatives from the industry who have experiences with hiring and working with graduates from the Engineering Physics program. The interviews with the students and the instructors were identical in questions, in order to explore potential differences in how the two groups perceive the program and, in the student's case, what they want to get out of it. The interviews with the industry are instead focused on defining what changes they think are important in order to maintain and improve the quality of the graduated engineers.

Since the group of interviewees were relatively small, at least for the student group, we dare not to make any detailed conclusions, but what we want to do is to clarify what the condition of the general impression of the program is, and for this we need but a indicatory test, and we will treat the results as indications rather than proven facts.

The students were asked to determine whether their education is relevant for a career in industry and/or research. Furthermore they were asked to answer questions about how they experience the balance between subjects in their education. Apart from this, they were also asked to define what changes they would like to make to the program in terms of adding or subtracting different subjects in terms of hours and credits spent. The subjects were divided into fundamental and applied mathematics, physics and mechanics. An important result here is that most students feel that there is no shortage in theoretical knowledge, while the spread is much greater when it comes to the applied subjects. Here, we can almost identify a mirror image of the answers concerning the theoretical subjects. It is also interesting to note that most students think that the program has a lot of theoretical and fundamental mathematics. The same goes for when the students are asked to give guidelines for how to change the frequency of the different subjects. There is a clear tendency towards wanting more applications in courses, even though many students comment negatively on those courses that are today considered to be of a more applied nature. This raises the question of how applied subjects can best be treated to make a contribution to the education. Finally the students, with clear majority, deem the education to be relevant to both industry and research, but more so the latter than the former.

The instructors seem to agree with the students on the relevance of the educational program for a continued career in industry and research, but apart from that the perspectives differ greatly. The instructors mean to say, with a few exceptions, that there is a well balanced level between all the different subjects. The instructors also make no greater difference between theoretical and applied subjects. This mentality is not a sign to say that either side is wrong, but it definitely indicates a conflict of perspectives between student and instructor. Many instructors comment that they do not know that much about the program as an entity since they only teach one single subject, and this is, in our opinion, a very important notion. To create a well balanced educational program, each instructor must be aware of the existence as well as the workings of the other instructors, not to a great level of detail but to a level allowing them to tie their subjects together where they see fit. One result that differs greatly is the perceived frequency of applied subjects, which many instructors think is quite high, while the students believe it to be quite the contrary.

Comparing the students' answers with the instructors' it is obvious that these two groups do not fully, share a common view on what the objectives of the program are and how these should be attained. The perceived program relevance for careers in research and industry are displayed in Figure 4. The comparative results for perceived density of fundamental and applied mathematics, physics and mechanics together with the desired changes in respective subject are displayed in Figures 5-8. Of course the instructors have a greater experience in their respective fields, but the students are the customers to the educational program and what they perceive they are buying is a very important part of what makes up the nature of the program. It is in no way wrong to strive to reach a high level of theoretical knowledge during the education, but it must not be done at the cost of applying the attained knowledge. At the same time, it is understandable that many instructors shun applications, fearing that they will only steal valuable time and reduce the quality of the theoretical teaching.

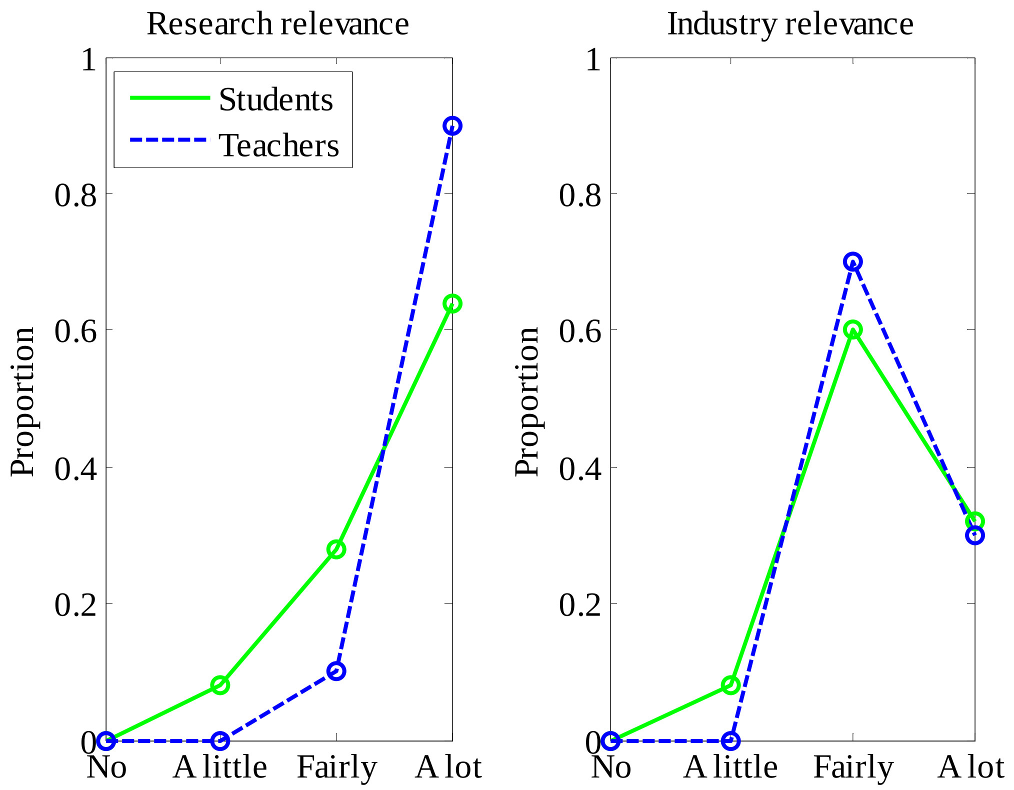

Figure 4. Perceived program relevance for careers in research and industry.

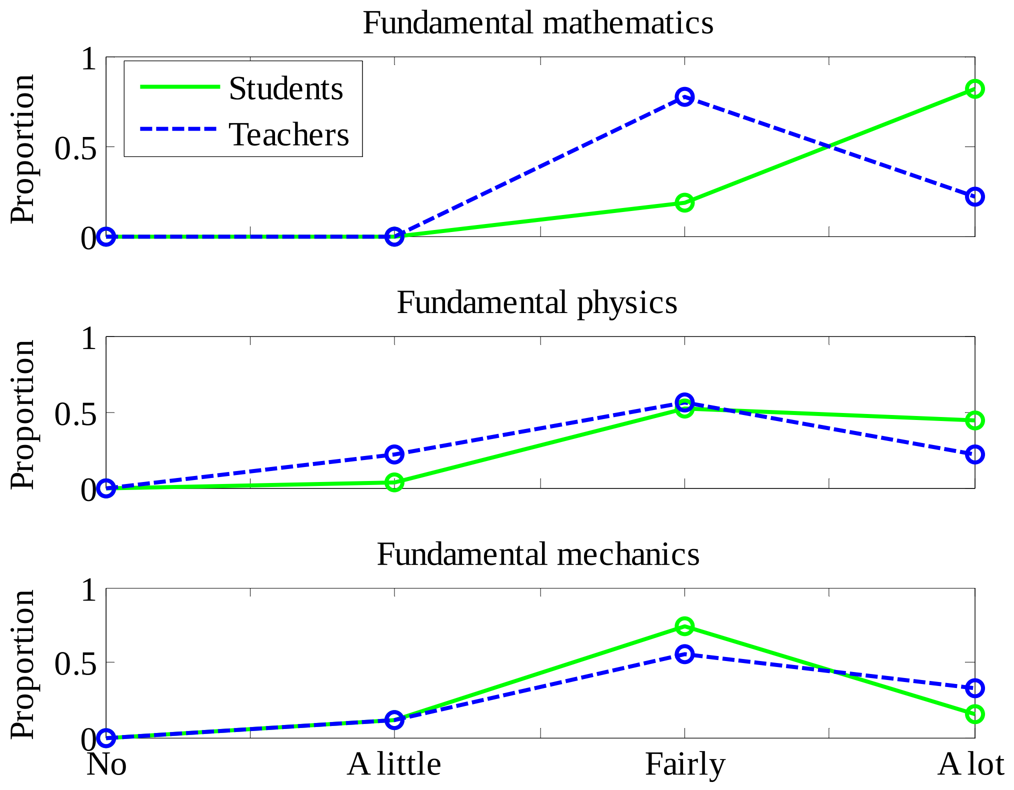

Figure 5. Perceived density of fundamental mathematics, physics and mechanics.

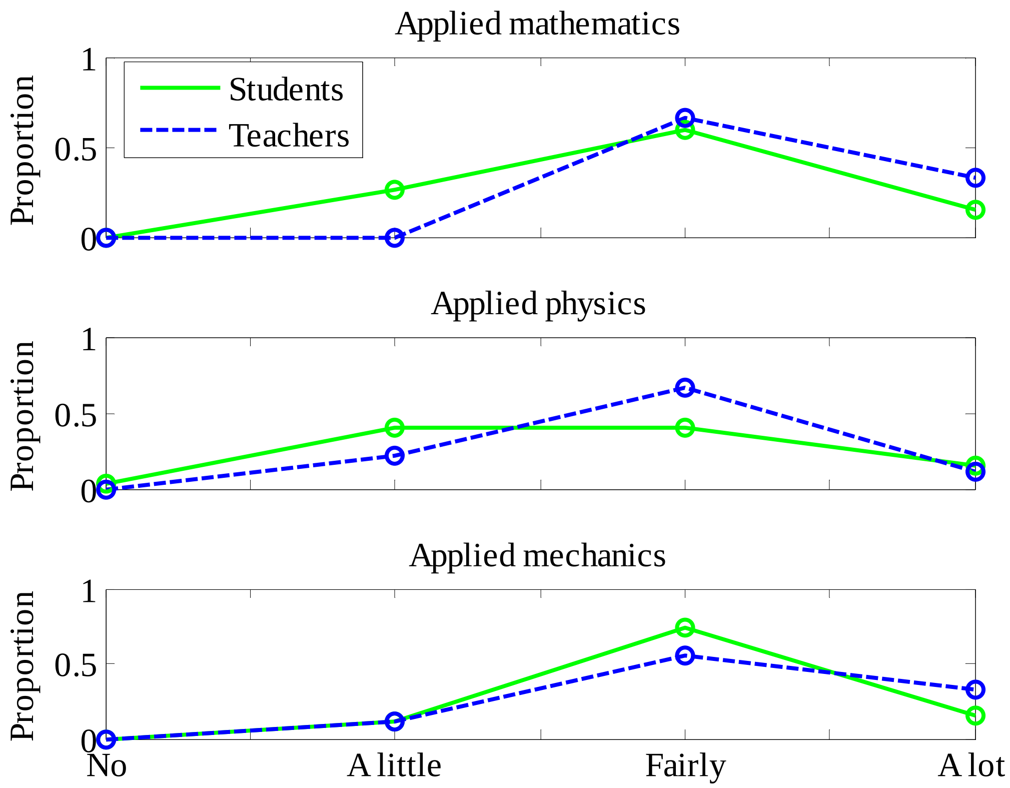

Figure 6. Perceived density of applied mathematics, physics and mechanics.

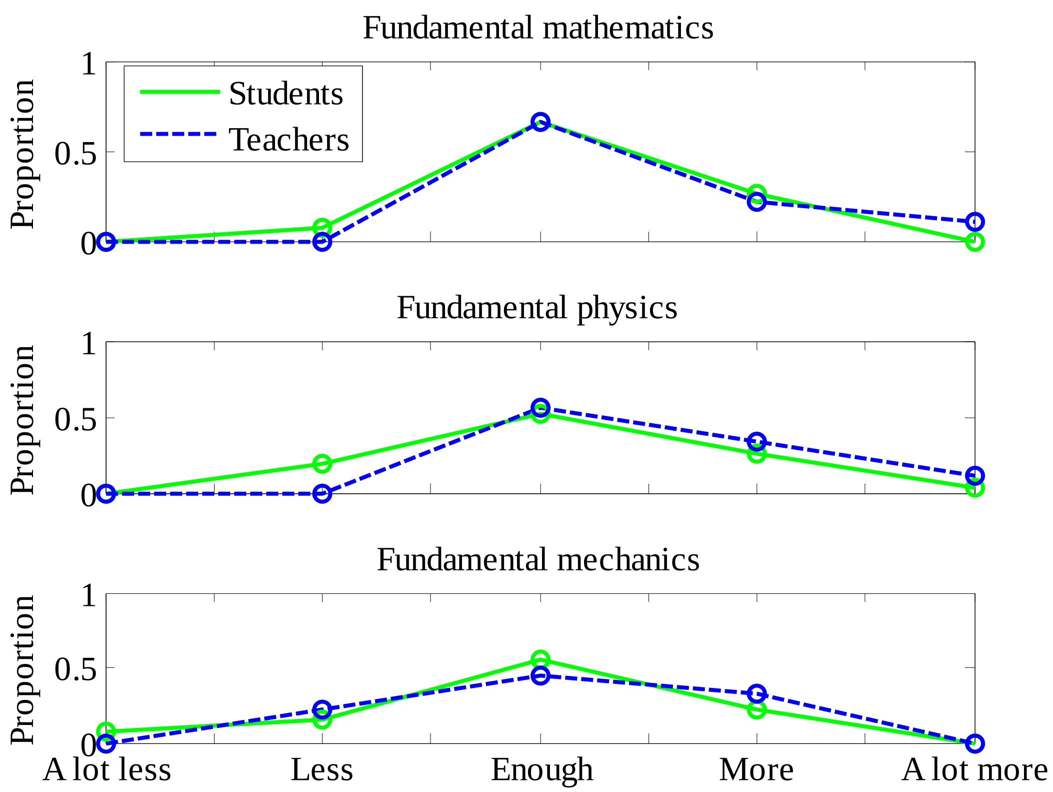

Figure 7. Desired changes in density of fundamental mathematics, physics and mechanics.

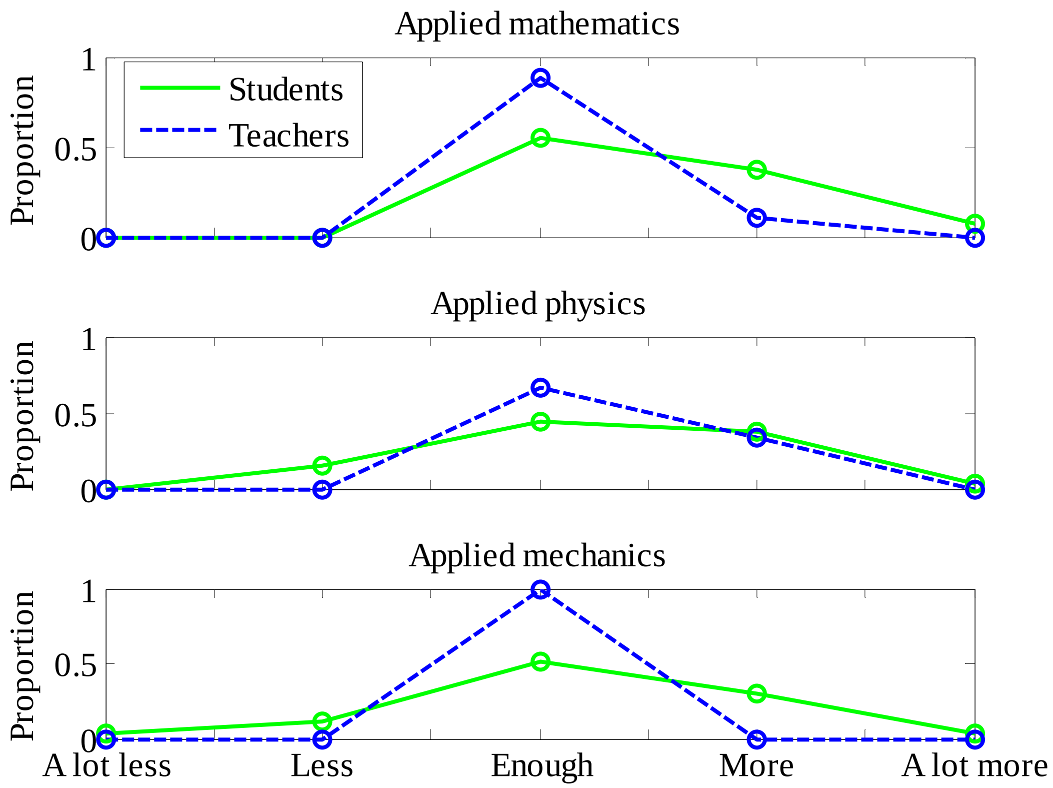

Figure 8. Desired changes in density of applied mathematics, physics and mechanics.

Finally, it is possible that many instructors, who are also researchers, easily end up prioritising their own subject. What becomes clear here, in view of the interview results, is that there is no widespread program mentality among instructors, and that is possibly due to the lack of a clear and well defined goal. This subject isolation can also be countered by allowing for creativity in between courses, encouraging instructors to make up combined assignments and teaching modules for the students.

To get an image of the perspective of the graduating students' future employers, we held a set of personal interviews with representatives from the industry. These interviews where structured so that the subjects were asked to name strengths and weaknesses concerning the quality of the graduates from the Engineering Physics program. Some of the interviewees were themselves old graduates who simultaneously gave a view of what the felt they lacked when they graduated. The interviewees were asked to judge what changes they would like to see in future engineering physics graduates. What came out most clearly, were the needs for improved skills in problem formulation, system perspective, group projects, leadership and presentation technique. One interviewee declared a "need for the graduating engineers to be able to know what questions to pose in order to achieve relevant information, and how to treat a problem in an economically efficient way to get a result that is good enough". This emphasises again the need to enhance the system perspective, at the same time as it points to the need for relevant and realistic problems to be handled during the education. It is easy to find the right answer in an isolated environment, but to find a good enough answer in reality is something totally different. Apart from this, the interviewees agreed that the graduates from the Engineering Physics program were of high standard when it comes to analytical skills, subject-related knowledge and problem solving.

Structuring Sub Problems
With experience from the interviews, it has become possible to pose a couple of sub problems, which can than be treated individually and collectively to find an optimal solution for the program structure.

First, and most important, is the question of the program formulation. In order to create a feeling of solidarity within the program, it is crucial to have a core formulation to gather the educational activity around.

Second, the adjustment of balance between theory and application must be well tuned. Many students ask for more applied science, while many instructors fear a loss of theoretical knowledge if more time is dedicated to applied science. Even when introducing applied science, it is vital to make a difference between *learning how* and *learning why*. It would be easy to resolve to teaching how something works only, but than the theoretical knowledge of that teaching is lost and degraded to a simple manual on how to reach an answer given specific parameters.

Last, but definitely not least, there is the question of how to connect the three major blocks of mathematics, physics and mechanics in the education and to allow for a more holistic perspective on the entire educational structure and not only on the separated course blocks.

Adjusting for balance between theory and applications contra system- and detail perspective, we find ourselves targeting a system perspective in the middle ground between theory and application, as displayed by the cross in Figure 9. With this said, we do not aim to avoid details, but upon working with details our goal is set on relating these to a larger system perspective. Hence, the system perspective is to be reached via detailed examples from different areas.

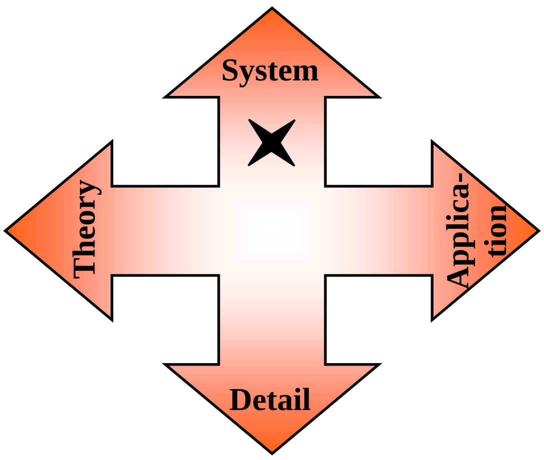

Figure 9. Desired target point, marked by the cross, of the evolved Engineering Physics program.

Making Priorities
In changing any organisational structure, it is relevant to make priorities and set up partial goals to support the greater change. In doing these priorities, we must begin with prioritising the constraints laid upon the entire changing process. In our case we make it a priority to preserve the good name of the education, and the core strengths of the current structure. At the same time we want to evolve the education given by the program, and to tie it together in

a consistent way, in which case we need to make the instructors enthusiastic about the process and get their creativity going. Here we believe to be to our advantage that the product orientation we want to implement is of an abstract nature, since this drastically cuts the costs of introducing them. This might be an interesting note to other programs as well, since there is no contradiction in adding abstract products even if the core activity is centred about physical products.

To be successful in implementing an interconnected CDIO-based curriculum, we believe it to be crucial to start out in a small scale and encourage joint projects such as the one between the two courses *Mathematical Methods in Physics* and *Numerical Methods* mentioned earlier.

Summarising this, our first priority will be to adopt the current curriculum to a CDIO-influenced approach, in order to lay the foundation down and prepare the program for further changes ahead. This way, we can maintain that which is good today, and at the same time start improving the program so that it turns out even better tomorrow. With this in mind, it is not to be said that no changes will be made. On the contrary, changes are needed, but since the curriculum today is so extensive it is more a question of how to highlight the bridgework between the different courses than how to incorporate new areas into the program. Therefore we believe that most changes can be made without altering the curriculum significantly, since we can instead work to integrate the changes into the current course structure in a way that enables the students to learn both about the applications connected to their respective courses, but also about the connections in between courses.

Using this extensive platform to span the education across different fields allows for two new strengths to enter the educational structure. First out, this structure will contribute to an evolved system perspective on the subjects studied, but more importantly this wide perspective will allow for a strong interdisciplinary approach towards modern science and engineering, and this is a strength we believe to be a very important, and relatively unique, attribute to this program.

Core Program Formulation

Once again summarising what we have concluded so far, we now feel ready to present a core formulation for the essence and vision of the Engineering Physics program we wish to construct:

The Engineering Physics program is an engineering education dedicated to educating engineers in the area of mathematical modelling and simulation of real world phenomena and processes. The program is based on a very strong foundation in mathematics, physics and mechanics, combined with knowledge collected from the system perspective of several other fields of science. The students are educated in posing as well as solving complex problems from several different contexts in order to give a better perspective on how systems correlate, interact and resemble each other, and students are encouraged to take an interdisciplinary approach to science and in their own education.

This formulation can be perceived with the help of the figure from the introduction (Figure 1), with some small changes added. What we want to mediate and put our emphasis on is how the system perspective and modelling approach allows for an overview of related subjects, as portrayed in Figure 10. The figure is presented in relation to the categorisation model for 21st century engineers, as it is presented in part I.

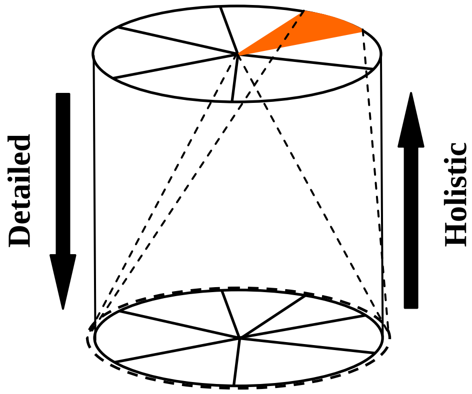

Figure 10. Desired program approach and perspective in relation to categorisation model presented in part I.

Part III – Formulating Strategies

We have formulated a question, and we have gathered information to answer that (the answer is yes if you feel you have lost track), and to treat that question. Next step is to elaborate on how we can reach the goals we have formulated, and how we can construct the program to which we have formulated a core. Following below are a few strategic steps in how we believe we can improve the Engineering Physics program and introduce CDIO elements into the curriculum. As mentioned earlier, we have chosen to focus on the implementation of the second and fourth chapters of the CDIO syllabus, since we believe that the other chapters do not require any special treatment upon implementation. All the same, some elements from other chapters will appear in connection with other elements.

Uncertainty and Open Answer Questions

To create a more dynamical learning environment, it is important to learn to deal with uncertainty. This does not mean that there should be any uncertainty about the lectures, but the homework assignments and lab assignments. One example of this is a homework assignment in which the student is asked to describe a physical environment first with words, and thereafter using mathematics. In this way the students is confronted with the problem of using mathematics to create a simple but consistent model of a real-day phenomena and/or environment. Focusing on uncertainty there is also the issue of handling uncertainty in measurements, test results and modelling which can be treated during lab assignments where the students are asked to judge the quality of their own or someone else's work.

Correlation of Courses

We believe that joint projects and assignments between courses are a good way to create a greater understanding of the mutual support and correlation between different subject areas in mathematics, physics and mechanics, as shown in Figure 11. This method can be used on the current curriculum to find synergies between subjects and to explore these synergies with home assignments and smaller lab assignments. This method has already been implemented in one example, mentioned earlier, with a joint lab assignment between a mathematical physics course and a course in numerical analysis. It is also possible to use the competence of extern researchers from other academic divisions. One example of this is an introduction level course in electrical circuits, where a professor in biological physics will hold a lecture on how electrical circuits can be used to model nerve cells and nerve circuits.

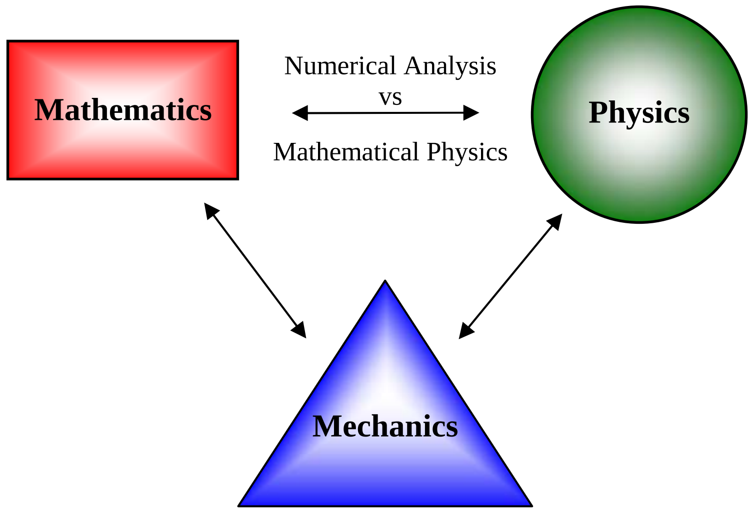

Figure 11. Finding innovative correlations between courses in the core subjects.

Perspective Courses and Modules

To give the students a sense of orientation between different academic disciplines early in their education, it is vital not only to focus on the current details, but to allow for a longer perspective. This can be achieved by using perspective courses early on in the education to relate the education to front line research areas, but also to industrial applications. This allows for a learning process with strong relations to external and societal context early on in the education, where it can influence and encourage the student in a wider way of thinking about engineering and model constructing. At the same time, having a good understanding of how the fundamentals relate to current research and industrial applications also leads to a bridging and evolving of the students' fundamental knowledge. The perspective courses can also be used to provide an umbrella to span and connect to the rest of the program structure.

Industrial Guest Lecturers and Problem Modules

During the specialisations, and perhaps even during the end of the compulsory block, it is extremely interesting to invite representatives from the industry, or researchers other than those involved with the course, to speak about how they use the material from the course in a actual context. This is possible in almost all specialisations, and it is always much appreciated. For example, in a course not typically covered in engineering educations, such as the one in financial mathematics and financial derivatives two guest lectures are given with representatives from a large company in the energy market, and from a leading Swedish bank. This procedure is also used in a course in optical physics, where several guest lecturers are invited to a longer seminar where they elaborate on how they make use of the contents of the course in their respective businesses. This is an efficient way to add business- and societal context to the course material, and it can easily be followed by a homework or lab assignment based on a simplification of the application presented. Apart from this, the original instructor can offer further reading in the form of papers or articles concerning the subject handled during the lecture, so that interested students can easily attain more information, outside of the course curriculum. In connection to this, the instructor can also continually encourage the students' further knowledge exploration by hinting about where to find suitable sources of information. It is important to strive to wake the enthusiasm and creativity of the students so that they themselves take a practical interest in their own learning.

Yearly Project Assignments

Repetition is crucial in qualitative learning, and to combine repetition with system thinking and the creation of a strong program mentality, we pose to introduce a set of project assignments during the educational program. The idea is to introduce one project each year, and to allow for the responsibility and freedom of the students to increase continuously in terms of group orientation, planning and execution during the different projects. To begin with, the students get a work plan and a predetermined group role orientation, and during the later projects the project structure is less predetermined, so that the students themselves must assemble their group. Apart from being an exercise in project management, the students are provided with an open question that requires them to use knowledge from their courses during the past year. This question should also be posed so that it has more than one explicit answer, forcing the students to deal with the uncertainty of real problems. To improve the quality of these projects even further, it would be possible to add elements from future courses, so that a perspective element is added to the project. These projects are a perfect way to introduce the students to interdisciplinary thinking, although this should be left for the last project, so that the project experience is well established as such an element is introduced. The last project could also be more strongly connected to industrial companies, in order to allow for a greater insight in the applications of the subjects taught during the courses of that year. It is of the outmost importance that these projects, however self-contained, are not separated from the rest of the program curriculum. The point of this strategy is to integrate project work within existing courses, and relate these projects to the entire educational structure in a holistic way.

Interactive Lab Assignments

During the research interviews with the students, a clear opinion was formed against the lab assignments included in the courses today. In fact, before defining CDIO as not being a plan to introduce more similar lab assignments into the program, some students were directly opposed to allowing for more applied science. This is a very alarming indicator, and it points to great weaknesses in the current lab structure. As it turns out, most lab assignments are based on clearly and rigorously prepared one-task problems to which the students already have the intuitive answer provided from the lectures. The lab assignments should be altered, adding a lot more uncertainty, and not as clearly posed instructions, so that the students must achieve knowledge of how to conduct the assignments themselves. Also, the assignments should cover a greater variety of procedures, where measuring should have a more prominent role in the workload. It is not always utterly important that the students arrive at the exact right answers with a level of significance reaching to the power of minus 9. In fact, we believe it is more important to allow the student to find their own way, and in the end understand why they did not get the exact correct answer, unless of course they did any way. Also, to connect further to the CDIO-syllabus, it is important to incorporate open questions into different lab assignments. This is especially applicable to computer assignments, where a constructed model can be questioned from a stability point of view with different potential influences. Interactive lab assignments also provide an opportunity for the students to learn how to judge quality and validity of results, in order to develop their engineering methodology.

Competitions as a Learning Instrument

A few courses at the Royal Institute of Technology use competition to encourage students to think outside the box. Two examples are a course in robotics and autonomous systems and a course in game theory. In each course the students design a product that enters a competition, the robotic students design football playing robots and the game theoreticians design playing algorithms that meet each other in a certain designed game. Both these courses are elective, and none of them is related to the departments presently engaged in the program educational structure, but it is our belief that similar competitive moments can be introduced in several other contexts.

Prioritising and Planning

As mentioned earlier, change requires prioritising. To ensure a qualitative improvement of the Engineering Physics program, we think it is important not to try to change everything at once. Instead, we suggest a model were the strategies presented above are introduced to the instructors, who in turn can pick, choose and suggest further ideas for the improvement work. That way, we make sure that each instructor feels that his or her subject is treated with respect, and we can also gather information and thoughts about the program continuously and from as many different perspectives as possible. No change, however ingenious, will ever hold if it does not have the support of the people involved in it. As of today, the compulsory block and the specialisations have gone through a change in writing learning objectives for their courses. This is a first trembling step in a series of changes, but more importantly it is a first glimpse at the possibilities of furthering the engineering education within the Engineering Physics program, something we hope several instructors will see and appreciate.

What is so Special About Engineering Physics?

Studying the suggested strategies for beginning the implementation of CDIO at the Engineering Physics program, the next step of interest is now to try to conclude what makes Engineering Physics so special compared to other engineering educations. As can be seen in the above mentioned strategies, many goals and methods agree fairly well with those of the CDIO-syllabus, given one crucial assumption: The product orientation of the Engineering Physics program is mostly an abstract one. In spite of this, it is still possible to adopt CDIO and reap the advantages of doing so, without having to work with only physical products.

Finding Synergies

As we pose to work with an abstract product orientation, focusing on models and simulations, it becomes more important than ever to look for synergies in the educational work. This means not only synergies between subjects and courses, but also between specific educational strategies and their effect on for example the program mentality. Greater project assignments, course correlations and integrations contribute to building a stronger program mentality, in which students and instructor can experience a “we-feeling”, enhancing the learning process greatly.

The very core of the program can actually be strongly related to the aim of finding synergies. The student is encouraged to look for and recognise synergies between different problems and different models, in order to be able to adopt their problem solving to a dynamical environment. This should be encouraged by studying, for example, the similarities, differences and relations between different prediction models. This knowledge includes not only what characterises each model, but also how they relate to each other and how models from one subject group relates to those of other subject groups, as Figure 12 suggests. The focus here lies more on the nature of the correlations than on each specific subject, and it is interesting to note the uniqueness of each correlation and the multitude of possible correlations. Experiments can be conducted to mix different model approaches or simply try to use one approach to solve a problem from another discipline than it was originally intended for.

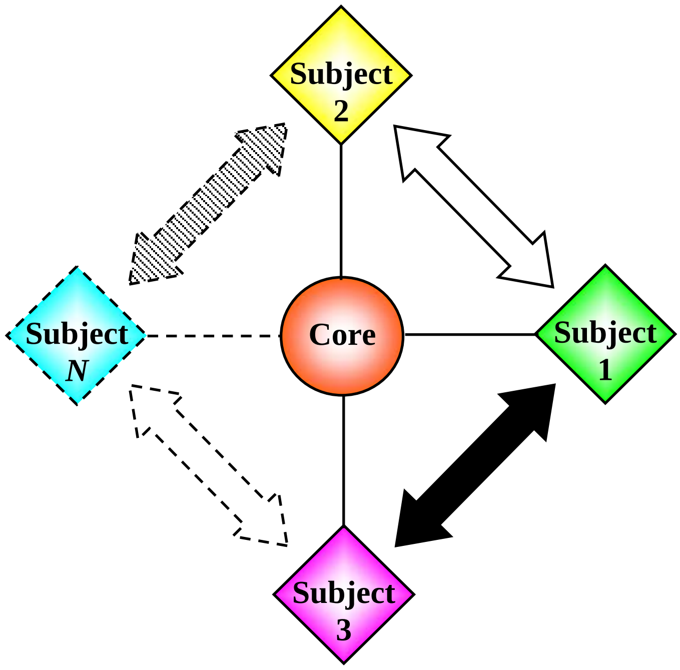

Figure 12. Correlation of subjects within the Engineering Physics program.

Educational Programs and Trademarks

Engineering Physics, just like Vehicle Engineering or Electrical Engineering are not only educational programs, but also trademarks of the engineers they produce. In this context the Engineering Physics program is a supplier while research and industry are customers to that supplier. As an educational program changes, the effect of the trademark is delayed, and it is hard to say exactly how any larger change effects this trademark. Engineering Physics for one, has a trademark which is somewhat contradictory to its name, if you chose to associate physics to theoretical physics and quantum theory only. Graduates from the Engineering Physics program are known to be fast to adopt, and easily be able find their way in a new environment. This is a flattering reputation, which further strengthen our belief in centring the program around the concept of modelling and simulation.

Although the program might not resemble what some academics would believe it to be, it is still a strong trademark, and that is something we believe is extremely important to nourish. In order to do so, it is important not only to define the strengths and weaknesses of the trademark but also the opportunities and threats, that is to do a SWOT analysis of the trademark in question. We have clearly found what we believe to be the program's strengths; the width, the approach to mathematical modelling, the rigorous mathematical fundaments and, not to forget, the students. The weaknesses are again the width, the lack of a single strong sector with connected and interested companies. The opportunity lies within the yet unfulfilled possibility to take advantage of the system perspective to strengthen the approach towards modelling and simulation. The threat lies in the idea that the program needs a physical product to focus on, and thus must adjust itself to work in competition with already established educational programs on a saturated market. It is not the product as such that poses the threat, but rather the risk of overemphasising the focus on the product, thus losing the general approach and the system perspective which we consider to be foundations of the program's strengths today. Bearing this in mind, another threat lies in the lack of program mentality among students and instructors, but this can be countered by the enormous potential, allowing for an opportunity to establish this mentality by emphasising the program over the single courses.

Conclusions

The CDIO-initiative is aimed at strengthening engineering educations, but it is at the same time a rigorous register of what we want from a qualitative education. Engineers are not the only ones who need to understand their own education from a wider perspective, and the CDIO fundament actually provides a self contained description of what we expect from people educated to work with the development of technology or science in any fashion.

Implementing CDIO into a new and yet unfamiliar program environment can be done in several ways, and it is a very delicate process. One way of doing it is by reforming the program so as to resemble a classical engineering education in as much detail as possible. This method has proven to be strong and successful in several cases, and it clearly represents many of the values of the CDIO-initiative. Another way of approaching the problem is to reform the elements of the CDIO-syllabus by weighing them in relation to the program structure and goals, in order to use CDIO as a technique to improve the strengths and repair the weaknesses of the original program. We believe it to be very important to allow for, and even encourage, a great diversity among the engineers of the 21st century, which makes it imperative to adopt CDIO with consideration to the program goals and core formulation.

Comparing the Engineering Physics program to the Vehicle Engineering program it becomes apparent that many CDIO elements can be implemented in both the programs, but in different ways and more importantly in different amounts. We have found that the Engineering Physics program and its essence make it suitable for an implementation with a greater focus on the second chapter of the CDIO-syllabus. In order to work closely with what we have assessed to be the core which makes the program strong in terms of educational quality, we have chosen to enlarge and focus on the CDIO-syllabus elements concerning modelling and simulation. In this way, we have constructed an abstract product orientation, around which we mean to construct a CDIO-integrated program. To aid this, we suggest that implementation is made on a step-by-step basis where integration between courses and perspective courses allow for a harmonic adoption with a preserved core and trademark. Although CDIO undoubtedly strengthens the educational structure of a program, it is also important to pose the question of what the vision of the education is.

Although there are several Engineering Physics programs in Sweden, and in the rest of the world, it will never be our goal to make them all equal and to provide an ultimate answer for what any Engineering Physics education should look like. Instead, it is our hope that this paper can inspire other program developers to look for the core qualities of their programs, and to use CDIO to enhance these qualities while creating a robust and successful engineering education.

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