AC 2009-941: EDUCATION FOR PRODUCT INNOVATION: A "GOOD PRACTICES" REPORT

Martin Grimheden, Royal Institute of Technology

Education for Product Innovation – A ‘Good Practices’ Report

Abstract

This paper presents results from a study of good examples of education for product innovation. A selection of exemplifying courses, modules, exercises and projects are presented. The selection is made to show examples of good practices which could easily be integrated into existing courses and programs.

The Product Innovation Engineering program, PIEp, is the initiator of the study and the overall aim is to produce a state of the art report to be used in future course and program design in product innovation, within the Swedish PIEp network.

In the study, three subject areas have been in focus: creativity, innovation and entrepreneurship. These focus areas have been applied primarily on higher engineering education and on programs of product development, engineering design and mechanical engineering. The study summarizes current status of research on education in creativity, creativity training and education in product innovation in general.

Introduction

The Product Innovation Engineering program (PIEp) is a Swedish national research and development program with the purpose of enhancing product innovation capability within Swedish universities, companies and organizations^{1,2}. This paper presents early results of an international study of courses, course modules and educational activities with the purpose of finding best-practices to serve as role models for the creation of new educational courses and programs within the Swedish PIEp universities.

In this study, three subject areas have been in focus: creativity, innovation and entrepreneurship. These focus areas have been applied primarily on higher engineering education and on programs of product development, engineering design and mechanical engineering. A literature study is presented which summarizes current status of research on education in creativity, creativity training and education in product innovation in general. The literature study moves on to bridge from creativity to product innovation by presenting research on success factors for product development in terms of organization and environmental factors.

Product Innovation Engineering program, PIEp

In 2005, representatives from the Royal Institute of Technology (KTH) in Stockholm, Sweden, took the initiative to start a large, national long-term program to enhance product innovation capability in Sweden. This program was finally launched in late 2006, with governmental funding, as the Product Innovation Engineering Program, PIEp^{3,4}. The program is organized as a network of researchers, educators and students in innovation engineering with the ambition of creating a system change toward innovation and entrepreneurship in institutes of higher education and research. The program encompasses three areas of activities: research in product

innovation, education for product innovation and industrial collaboration for product innovation. PIEp addresses and facilitates increased Swedish ability in innovative product- and business development. The program ranges from theory to practice, from research in innovation to directed activities aimed at strengthening Swedish innovative product development. PIEp is implemented through research efforts, educational efforts and development projects. The research efforts are necessary to develop a common platform, to gather existing, and generate new, knowledge about the innovator, the innovation process and the innovation system. Further, PIEp contributes to technical research efforts which are governed not only by the scientific questions but also more directly from a product and innovation oriented perspective. The innovation climate in participating companies is developed through research, development and directed activities such as creative sessions and the building of networks. See also^{5, 6, 7, 8}.

PIEp Education

The PIEp program is organized in five activity fields; two with a focus on process and organization oriented research (Innovation Knowledge and Innovation Management)⁹, two related to product- and business oriented development (Innovation Experience and Innovation Business)^{10, 11} and one related to education (PIEp Education)^{10, 11}. All five fields generate knowledge and feeds back knowledge and experiences to the other fields. Figure 1 below illustrates the ‘resource system’ or ‘learning cycle’ of PIEp together with some keywords and key activities of the respective activity fields^{12, 13}.

Figure 1. An illustration of the ‘learning cycle’ or ‘resource system’ of PIEp. The five boxes symbolize activity fields and the text in red shows examples of activities organized in the fields with results from these. Results, experiences and competencies should ‘feed into’ the neighboring fields, as shown by the grey arrows.

The main activities of PIEp Education involves new courses in innovation engineering, a research school for doctoral students, exchange programs for students, rotational programs for faculty and better utilization of all existing mechanisms for bringing ideas to market^{10, 11}. To

create a sustainable change of higher engineering education toward innovation, it is necessary to involve and include all teaching personnel in training activities. These activities are based on a number of training workshops where expertise from the entire PIEp is utilized.

The overall aim of PIEp Education is to lead and support a system shift of higher engineering education, toward innovation and entrepreneurship, and the mechanisms for this shift is applied on all levels in the engineering structure.

PIEp Nodes, International Partners and Innovation Friends

PIEp consists so far of six Swedish universities and two international partners: Center for Design Research at Stanford University and the Sr Kenny Research Institute in Minneapolis. Both international partners are in the US. A number of European and other universities are on the verge of signing up as additional international partners in the near future.

The list of PIEp Swedish nodes (node universities) is as follows:

- Faculty of Engineering, Lund University (LTH).
- Umeå Institute of Design, Umeå University (UmU)
- International Business School and School of Engineering at Jönköping University (HiJ)
- Royal Institute of Technology, School of Industrial Technology and Management (KTH)
- Luleå University of Technology (LTU)
- Center for Technology, Medicine and Health (CTMH)

The two international partners are chosen to complement the six Swedish node universities as follows:

- Center for Design Research at Stanford University (CDR)
CDR performs research and education in design, design thinking and creative methods for product development, innovation and entrepreneurship. Situated in the midst of Silicon Valley, one of the most entrepreneurial regions in the world together with well renowned research CDR provides invaluable input and reference for the Swedish nodes.
- Sr Kenny Research Institute (SKRI)
SKRI performs research and product development in the area of rehabilitation, well-being and medical technology in general. Integrating clinicians in the research institute, the SKRI bridges PIEp to both clinical research as well as one of the most active med-tech centers in the US.

Through these international partners, a number of further contacts – called ‘Innovation Friends’ have been established as potential future collaborators. The Hasso Plattner Institute of Design (the d.school) at Stanford University with their interdisciplinary focus, prototyping, social context and responsibility and the concept of ‘design thinking’ is a great role model for PIEp, as well as the new Product Design and Business Development Program at the University of

Minnesota with their focus on med-tech products, ability to attract local companies as sponsors and project owners.

The six PIEp nodes combined with the two international partners are chosen to provide complementary expertise in what we believe could be a future potential for product development in Sweden. The KTH node provides technical expertise in the design and development of complex, knowledge intensive products. HiJ provides the business and entrepreneurship aspect. UmU provides world renowned expertise in industrial and consumer design, with focus on interaction design, user interfaces etc. LTU and LTH both provide expertise in product development: methodology and tools as well as complements in several of the areas above. The CTMH and LTU node also provides an application specific area – medical technology or well-being. The med-tech focus is chosen as a large potential for Swedish product development, with several large companies based on innovative ideas.

The two international nodes complement the six Swedish nodes both in the process oriented perspective (CDR) and the application specific perspective (SKRI) by providing world-renowned expertise in both areas.

The need for new modules, courses and programs

As described above, the intention is to create a system change of higher education toward product innovation, synthesis, creativity and the promotion of entrepreneurship. As described above, most of these components exist within the PIEp network – or rather can be created in symbiosis between the various nodes. We believe that the combination of expertise from these nodes and international partners can create a unique synthesis for innovative product development.

We also believe that the first step of creating this system change consists of a phase of mutual learning, of understanding each other's focus and expertise. The second step in this process is to open up this mutual learning process for external input, learning from the best. The third step is then to utilize this input in the creation of a new generation of course modules, courses and program at our respective node universities where we utilize the input in the earlier phases. Without further ado, we therefore present results of this second step – our approach at 'learning from the best'.

Education for Product Innovation, the literature study

In the following, we present a list of courses, course modules and activities we have identified as valuable in the area of product innovation. In all cases, we refer to the respective articles where we have gathered the information for more information.

The table below shows an overview of the examples, and more extensive explanations are given below.

	Exercise	Reference	Scope
1	Candy Airplane Exercise	High, Mann and Lawrence ¹⁴	Exercise (few hours)

2	Spelling test	Weaver and Muci-Küchler ¹⁵	Exercise (few hours)
3	Parts Handling Exercise	Weaver and Muci-Küchler ¹⁵	Exercise (few hours)
4	Bisociation Exercise	Weaver and Muci-Küchler ¹⁵	Exercise (few hours)
5	Lego Robot Exercise	Shirley ¹⁶	Exercise integrated into a course (several weeks)
6	Pizza Project	High, Mann and Lawrence ¹⁴	Project (several weeks)
7	Ice Cream Project	High, Mann and Lawrence ¹⁴	Project (several weeks)
8	Teacherless education	Horner ¹⁷	Course (several weeks)
9	A patent on your resume	Segal ¹⁸	Course (several weeks)
10	IDEO vs stage-gate	Batill ¹⁹	Capstone course (several weeks)
11	Innovative thinking	Raviv ²⁰	Several exercises and projects (hours to weeks)

1. Candy Airplane Exercise

The authors behind the Candy Airplane Exercise discuss the conflict between traditional student views on engineering as very mathematical and rigorous with the proposed view of engineering as a creative field of study. They argue that the amount of creativity necessary to solve industrial problems is highly underestimated²¹. Referencing Higly and Marianno²² the authors argue that there is a direct line between increasing the creative input in student education and having students take more ownership in their projects – by expressing their unique ideas, and that they would feel more pride in their work. The authors have created, implemented and evaluated a series of exercises to promote creativity and problem solving. An underlying principle has been to move to areas of non-technical problems to be able to cope with student's variation in backgrounds and understanding of basics in a specific field. Three exercises are presented: the candy airplane, the pizza project and the ice cream project.

The candy airplane is a rather brief exercise, spanning from a few hours to half a day. The exercise can be described in three phases. First the students focus on the creative design of an airplane based on assorted candy and small office supplies. Secondly, the instructors announce that the design phase is over and a manufacturing phase starts. The students are now tasked with manufacturing as many planes as possible, identical to the first prototype while constantly being interrupted by process upsets such as loss of raw materials, employee injury etc. The third phase involves reflection and feedback.

2. Spelling Test

Weaver and Muci-Küchler have reviewed a large amount of literature in the area of creativity exercises and developed a series of exercises proven to be effective in providing distinct teaching points that can result in a student's ability to apply a particular technique to generate more creative concepts. In the article, the authors basically present three exercises: the spelling test, the parts handling operation and the bisociation.

The Spelling Test exercise relates to a previously documented exercise: The ABC's of Creativity²³. The exercise is divided into three parts – each based on a set of wooden blocks with

or without markings. In the first part, a subject is asked to form the word 'LIT' using a set of blank wooden boxes. In the second part, the subject is instead offered a set of wooden blocks with markings of letters – but with the letter 'T' removed. In the third and final part, a subject is first asked to spell a number of words using the wooden blocks before asked to spell 'LIT'. All words are based on letters on the given wooden blocks even if the letter 'T' is still missing. The authors perform this exercise as the basis of a discussion in a larger group. Typically, the first part is solved within a few seconds. The second part takes in average up to a minute while the third part takes up to 2-3 minutes. With this example, the authors show the concept of 'anchoring', meaning that the individuals tend to be fixed on one particular approach when solving a problem even when other solutions may potentially be better.

3. Parts Handling Exercise

This exercise is based on an exercise documented in¹⁴ called 'Keys to creativity'. The authors present a setup where a subject is presented with a number of artifacts such as a broom, a key ring, a chair, duct tape etc and then asked to perform a task with the equipment, such as retrieving the key ring without crossing a line on the floor. When performing the exercise with students, the authors show that the number of artifacts relates to the time it requires the subject to perform the task. Typically, a subject being given only the broom and few other tools are much quicker at mastering the task than a subject given more tools.

In their analysis, which provides a base for a following reflection with the subjects, involves both the need for a structured methodology versus a large number of tools, the need to master the tools and the need to be open to new ideas and solutions.

4. Bisociation Exercise

This is an exercise based on association and the possibility to combine several ideas into products. Typically, the authors first ask students to come up with as many new ideas for earrings as possible, within three minutes. Then, the authors ask the students to do the same exercise, but this time while thinking about the North Pole. Typically, the students come up with considerably more ideas in the second part, while thinking about the North Pole.

5. Lego Robot Exercise

This article presents results of an effort to adapt a course developed for training industry executives in creative teams into an engineering course for college students. The course covers aspects of a creative enterprise such as assembling creative teams, generating ideas, alignment of teams, customers, suppliers etc as well as planning, design, risk management, production and deployment. In this specific course, the design and construction of a robot based on the Lego Mindstorm system provides the hands-on exercises.

The uniqueness of this effort can be found in the authors' background with 35 years of experience in creative industrial enterprises such as NASA projects and experiences from developing courses in managing creativity for NASA's Jet Propulsion Lab, JPL. A particular focus in this paper is the notion of collective creativity, mainly meaning results from a group.

Even though creativity is generally viewed as an individual pursuit the author argues that groups of people can produce results that one person can hardly imagine, such as spacecraft, cathedrals etc. This leads to the focus on managing creativity – pursuing collective creativity then becomes an effort into leading and managing people and how to work in a creative team.

Contrary to many similar courses and exercises, the hands-on part of the course is rather small. This exercise is more seen as an exercise around which the course is built. The course is divided into a number of elements of a creative system: teambuilding, concept generation, achieve alignment, design, risk management, production, deployment and evaluation. Each element is covered by lectures, literature and student exercises. To bring realism into the project, each team is tasked with creating a business that should develop a concept for a robot, implemented with the Lego Mindstorm system. These robots should represent new concepts or businesses such as prototypes for spreading fertilizer on lawns.

6. Pizza Project

The pizza project is a multi week project. In the author's example, teams of four students each spent twelve weeks on a scenario where all design teams were contracted by an imaginary pizza company. All students kept thorough records in logbooks. The design teams were given a design brief in the form of a symptom:

“Customers of [the imaginary pizza company] are calling in to complain that delivery pizzas are arriving cold, and that grease is leaking through the boxes and staining tablecloths.”

The students were instructed not to focus on one single problem – the design of the pizza box, but rather to think more broadly, such as experimenting with pizza recipes. In the wrapping-up of the project, the students deliver professional presentations, present their problems and solutions and argue for their specific method.

7. Ice Cream Project

The ice cream project is similar to the pizza project regarding scope, time and student teams. The design brief is similar, describing a symptom rather than an explicit problem. This brief describes telephone calls from angry customers of an ice cream store describing their frustration when the ice cream they all have bought starts to melt before they reach their houses. Similar to the pizza project, the students are expected to deliver a solution to an imaginary board of directors of the ice cream business.

8. Teacherless education

This paper describes an experiment in educating students in creativity in a very innovative way itself. The author describes the problem with educating creativity and innovation – that the entire tradition and structure of higher education denies creativity by not promoting change. The author describes an experiment where he simply removes the teacher from the equation – thereby upsetting all structures and preconceived notions of how education is best performed. Basically, the course instructor provides the students with a course syllabus and then assumes the role of

mentor, coach and advisor instead of instructor. The students will have to completely manage the situation themselves, including leadership, knowledge acquisition and assessment.

In the paper, the experiment is very well described with excerpts of email correspondence between professors and students giving insight into how the course and experiment developed. While some students seemed to have problem with the leaderless course other students emerged to take responsibilities and develop their abilities.

9. A patent on your resume

The course presented in this article is focused on teaching the patent process and project organization. Students are well aware of the possibility of getting their own patents as a result of the course or at least getting a better understanding of how to apply for one. The author present results from previous course instances with product ideas of student teams which looks very promising. The course is given as a capstone course with the ambition of covering the ABET criteria related to skills in practical engagement with technical knowledge.

It is very interesting to see the approach of teaching the concepts of the patent process within a capstone course and having the students develop their own ideas and products. It is not difficult to imagine the student enthusiasm for the course – with the possibility of actually putting a ‘patent pending’ line in their CV.

10. IDEO vs stage-gate

This article presents an experiment where product innovation is taught in a capstone course using two different organizations for the product teams. The author is basically having the students choose one of two drastically different product development processes while taking their capstone course and having them reflect upon the importance of product development process or methodology for product innovation. The first model is a more traditional stage-gate process used previously within the course, and the second model is based on the well-renowned company IDEO and the model proposed by Tom Kelley^{24, 25}.

By showing examples of students who appreciate both processes, and with examples of students asking to change from the more structured to the less structured as well as vice versa, the author clearly shows that there are no right answers in the choice of process – just like there are no right answers in the design of a product. He concludes with “instructors are able to experiment and learn what best suits their teaching style and institutional goals” and hopefully the same can apply to students as well.

11. Innovative thinking

In this article Raviv presents results from several courses, workshops etc where he has introduced creativity exercises. Examples are 3-D mechanical puzzles, games, mind teasers, LEGO Mindstorms competitions and design projects. He further presents results and experiences from courses in “inventive problem solving”, “innovative thinking” and “eight-dimensional methodology for innovative problem solving”. Examples of course modules and exercises are:

The amazing maze, a hardware-based game for enhancing teambuilding, communication and leadership, 3D puzzles and similar activities focused on training open-mindedness.

Examples from PIEp – Nodes, International Partners and Innovation Friends

Beside the above, we believe that experiences from Product Innovation Education at our respective nodes and international partners are valuable for the educational community. Education at the PIEp nodes in this field have been extensively disseminated previously^{2, 11}, but in this article we'd like to mention specific input we have utilized from our international partners.

At CDR, Stanford's Center for Design Research as well as the d.school we would like to mention a few selected observations. At CDR, the concept of 'design thinking' is on everybody's forehead. Design thinking means a new way of thinking – creatively, outside of the box, radical, spontaneous, outright and innovative. The list of labels can be long. It can all be in the line with what we here describe as product innovation. Design thinking is explored, by several researchers, with the aim of finding, describing and assessing 'how designers work' when they do their best. Among results and research areas are factors promoting creative work, organizations for creativity and especially education for creativity.

We also put forward a specific course or focus of teaching found in a few of the courses offered by the d.school – design for extreme affordability. These courses are among the most popular at the d.school, which itself is one of the most popular and recognized institutions on Stanford campus. A typical course involves one large hands-on project focused on the development of a product for a third world country. In these courses and projects, students have to take into account very hard boundary conditions such as economy, access to electricity, water etc as well as manufacturing costs and usability. In our analysis, two factors are of relevance to understand the popularity – the limitation of resources and the sense of the customer. The customer becomes very real and the product developer soon establishes an emotional affection toward the intended user. The product is supposed to help a user, solve a problem and not simply make revenue. But also the fact that the resources are limited is an advantage – the complexity is reduced.

Discussion and results

First – a number of exercises are presented that can be characterized as fun, hands-on, innovative and almost crazy projects. These include the Candy Airplane Exercise, the Pizza Project and the Ice Cream project. In especially the later two examples, the students define the problem, and not the teachers. The students are given resources such as pizza, money for ingredients, and experimental equipment such as thermometers. The exercise is *fun*, the students gets to eat a lot of pizza. The students interact with faculty in a relaxed atmosphere: they give professors pizza; they share a meal together etc. All activities are very unorthodox and radical. The common denominator of these exercises is the notion of encouraging students to think freely and creatively by getting freedom to do so, resources and radical tasks.

In a second set of exercises, with examples such as the Spelling Test, the Parts Handling exercise, the Bisociation exercise the students are experiencing hands-on ways and methods to

think ‘outside the box’. In all exercises, the teachers shows the students how their creative thinking is limited and bound by a lot of external factors such as preconceived notions of how things are usually done as well as disturbed by too much information. The articles mentioned presents very easy to use exercises complete with teaching hints and past examples and experiences. All exercises seem to be selected after a thorough search and evaluation has been performed. All three exercises also can be used in a hands-on teaching of creativity – with a hands-on approach. The common denominator of these exercises is the idea of showing, by way of rather simple exercises, how our thinking is limited by outer boundaries.

Third, a number of exercises, projects and course modules such as the Lego Robot Exercise and the ‘Patent on your resume’-course clearly shows how student motivation for entrepreneurship and product innovation can be improved and enhanced by way of realistic examples, industrial relevance and non-academic motivation. In the cases presented here, students are exposed to real-life projects and are tasked with creating business plans for their product ideas. Lectures with extensive industrial experience provide realism.

In the Lego-example the author and class instructor manage to integrate extensive industrial experience into the course and exercises. She mentions that the lectures are ‘lavishly illustrated with actual examples, many drawn from the author’s personal experiences, particularly as the leader of the NASA Pathfinder Microrover team’. It’s not hard to imagine the student’s interest and enthusiasm of seeing the connection between their course, what they are currently studying and the relevance in a professional setting. It is also interesting to see the ease of use of the Lego equipment – each student team is basically provided with a kit and that’s it. No need for prototyping workshops etc.

In the ‘a patent on your resume’-example it is interesting to see the approach of teaching the concepts of the patent process within a capstone course and having the students develop their own ideas and products. It is not difficult to imagine the student enthusiasm for the course – with the possibility of actually putting a ‘patent pending’ line in their CV.

The fourth and final category is illustrated with the ‘teacherless education’-example. This is an example which could be characterized as ‘live experimenting’, meaning that the instructors are performing an experiment with their students without either prior information or consent. In the paper describing the experiment, the author provides all information necessary to reproduce the setup, including the course curriculum and other info. Even if the experiment itself is a major effort to reproduce, the article could be used in education to elaborate a discussion about education in creativity.

Conclusions

Our ambition has been to find, investigate, evaluate and present what we have defined as role models for education in product innovation, to serve as examples for our continuous work with developing higher education within the Swedish PIEp program. In this paper, we have intended to present results of this study and provide a list of these examples and role models.

In the study, three subject areas have been in focus: creativity, innovation and entrepreneurship. These focus areas have been applied primarily on higher engineering education and on programs of product development, engineering design and mechanical engineering. The study summarizes current status of research on education in creativity, creativity training and education in product innovation in general.

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