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RETROSPECTIVE STUDY ON TEACHING ENGINEERING DESIGN AND PRODUCT DEVELOPMENT

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ABSTRACT
A professional designer is able to make long reaching and correct conclusions from seemingly inadequate amount of information available. He/she has a comprehensive mental model on the topic in which he/she is working on. All of the information within the context is observed through this model. From the higher education pedagogy point of view, this kind of holistic insight belongs to the most difficult topics to teach. One approach to solve this is to completely abandon the conventional top down approach to curriculum planning. This approach however sets requirements on facilities, increases the amount of education personnel and is often impossible to accomplish parallel with conventionally arranged teaching modules. Instead of one big leap, there is also a possibility for an incremental change. In this paper, the elements of incremental change are defined and experiences on ten years teaching development work are analyzed.

Keywords: Systemic knowledge, learning process, knowledge content, student, community

1 BACKGROUND AND MOTIVATION

Our teaching context is in higher education, third and fourth year students aiming for Master of Science in engineering design and product development in Tampere University of Technology. Our university has a long history of intense collaboration with heavy metal, mobile machinery, electronics and paper industry. Therefore it is important for us that the students apply skilfully the theories, methods and processes we teach. In this paper we examine two courses and the basic information is presented in Table 1.

Table 1. The courses with basic information

Course	Semester	N:o students	Credit points	Lectures (h)	Teamwork / individual work	N:o lecturers
Modularization	6	50-60	5	30	6 h / 90 h	2
Product Development Project	6	30-40	5	12	113h / 5 h	2

The professional designer is able to classify and evaluate the information, build a comprehensive mental model and to make long reaching and correct conclusions from the data available. Professionalism in design requires the designer to have a holistic understanding on the topics to such extent that for bystanders it could look like work of a magician. This kind of insight in product development is one of the most difficult topics to teach in the higher education.

Tylers´ top-down rational [1] is applied which results teaching specific skills on each course. For teachers it is practical because each, separate course is easier to manage and teach than courses with lot of interdependencies. The skill based division isolates the courses from each other, does not support applying skills from another course and inhibits the emergence of the holistic insight for the student. The reductionist approach results in students having fragmented knowledge base, where the methods and theories appear for students as islands in the sea without connections, relations and dependencies. There is also a risk that this approach educates experts, who believe that they do not have to consider anything outside their narrow scope of expertise. One approach to solve this is by totally abandoning the reductionist approach. This new approach sets requirements on facilities, increases the amount of teaching resources, and is often impossible to accomplish parallel with conventionally arranged teaching modules. Instead of one big leap, there is also a possibility for an incremental change. In this paper, we observe and reflect based the experiences during ten years teaching development work and define the elements of the incremental change. The approach for product development education using conceptual modelling, knowledge integration and metacognition is presented in E&PDE conference 2012 [2]. In this paper, the aim is to present a set of practical solutions, which have taken an advantage of the understanding provided by this approach.

2 RESEARCH METHOD

This research applies educational design research methodology (EDRM) [3]. It was not chosen initially, but as our knowledge on design education increased during the years we realized the EDRM serves our research very well. Our research group has initiated six teaching development projects, which have been reported in international conferences during years 2002-2012. We now proceed as our approach expects, and elaborate this research by drawing a conceptual model of these practical solutions. Then we examine the reference projects in relation to the conceptual model in figure 1. Some of the research data is based on the course evaluations and grades required by our departments´ quality system for education. Some data is based on our own field notes, reflecting and observations during the years.

3 RESULTS

Retrospective study reveals that there has been development in teaching, and change is observable in teachers' attitudes and perceptions. The teachers consider themselves as experts on the topic to whom the teaching is only a minor part of working as expert during 1997-2002. Initially, the objective was to find more effective ways to transfer information and seek alternative ways to use resources. The mode of action was to seek improvements using restricted stand-alone projects. For example, one topic of the course could be isolated and taught differently leaving the rest of the course unaltered [4,5,6]. There was a lack of critical re-thinking towards the teaching material and textbooks. The material was not considered to be of high importance. This is what we call an "efficiency seeking stage", and according to our observations, similar acts of development are typical in the area of teaching product development from the engineering perspective.

After six years period of teaching product development, there is evidently a change in direction. The teacher-centred learning process, and especially the assessment of the learning was stated as an issue. The focus was no longer the topic of work effort of the teachers, but the ideals and values in the teaching were exposed in discussions [7,8]. This is what we call in this paper a "goal seeking phase". At this stage, the teachers no longer consider themselves as neutral experts. Instead, we as educators leave the comfort zone and ask "are the contents of teaching and evaluation criteria the right ones" and finally "are we the right people to assess proceeding of the students". The latter question lead to the next experiment, where we replaced the conventional individual assessment of students 'made by teachers' by measuring the added value in the group work effort. This required to create a new learning community with its own rules and values in the context of this particular course. To facilitate this and ensure that all of the teams possess a required ability for internal assessment, we assembled the groups using a framework of team role profiles [9].

During ten years, there has been a slight change in our students. The ratio between male and female students balanced towards fifty-fifty situation, and the focus area of interest among students has shifted from mechanical construction to more general product development issues. Within the first years of this path, we were very much concerned of the fact that year after year we have more students who do not have the experience of disassembling and assembling any technical artifact like a motorbike. This is now compensated with simulation game where the students experience similar challenges than with actual products.

One area stayed more or less untouched. The textbooks as the way of representing the new product development and product structuring have remained the same. Gradually we accepted that we have to change the way of presenting our teaching topic. We noticed that the contents and the theoretical orientation of the textbooks no longer correlated with the insights within product development. The textbooks cover mainly new product development as known as "Greenfield" which from our experience is seldom the case in industry. Typically, a company has some earlier products in production, the technical solutions of earlier products are used as a starting point for a new product. This type of product development is what we call "Brownfield", which refers to actions not starting from the scratch. Due to the changing environment, we chose to teach technical artefacts as systems. The results of this thinking we presented year 2012 [2]. The progress during the years is shown in Figure 1.

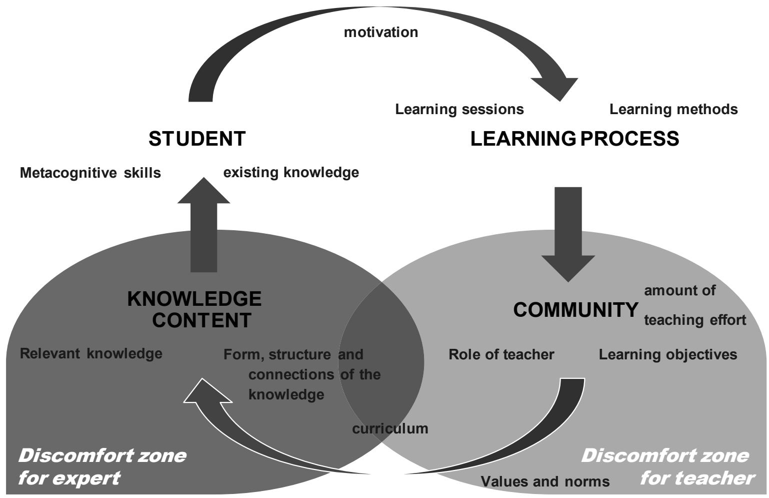

Figure 1. Conceptual model on the progress of the teaching development. Initially, the focus was on to teach certain skills with minimum amount of teaching effort. The next phase focused on the learning process, on the roles of a teacher and a student, and on the learning objectives. In the last phase the focus was on the purpose and meaningful teaching and learning in terms of knowledge building capability in industry

3.1 Efficiency seeking phase 2002-2007

In the very beginning of our teaching development, the objective was to find a solution to the question: **"How to execute design education effectively and efficiently for hundreds of people with minimum resources?"** The focus was on student motivation and on the efficiency of the learning process. As a result of this problem solving, two different simulation games were developed; one for the university students and another for the practitioners in industry. Quantitative data was gathered at the university from exams. The results were examined comparing results influenced and not influenced by the simulation game. Especially the learning experiences of poorly motivated students were remarkably better when using the simulation game [10]. The data from the industrial practitioners is based on observations while using the simulation game. The results reveal that simulation games are a valuable method for design education. With skilful design and scoping, simulations improve learning, and reduce the amount of teaching resources needed for education.

The automatic peer evaluation experiment [6] was a step further in abandoning the teacher centric assessment. It is based on peer evaluation experiment (see chapter 3.2). The core of this system was a stepwise algorithm, which sorted out the most reliable evaluators and then calculated grades according to their evaluations. First, personal credibility factor was calculated for every student according to how his/hers own answers were evaluated by fellow students. This calculation was followed by a second one, using the credibility factors as weight factors to minimize the effect of students who seem to have poor knowledge on the topic. The peer evaluations made by student were then taken into account depending on the credibility factor. If the deviation between different peer evaluations remained within threshold, the system automatically set grade. Only if evaluations from students with high credibility differed remarkably, the teacher intervention was required.

3.2 Goal seeking phase 2007-2010

In this phase we focused on the learning process, on the roles of a teacher and a student, and on the learning objectives. In the peer evaluation experiment, the students took part in two-phase exam. In the computer aided learning environment, every student was given randomly chosen assignments such a way that no students had same assignment. After the students received the assignment he/she had given time to answer it. Students were allowed to use textbook and other material in the exam and they could make their assignments on their chosen time under a period of one week. On the next week, they were given the answers of the other students to be evaluated, corrected and completed. The half the grading was based on the second phase, which was assessed by teachers. First tests using this approach were made in 2003, and five years later it had became a standard procedure on multiple courses [7]. In traditional teaching the assessment is seen only as a test of learning and it does not consider the assessment as a tool for managing the students learning. Current assessment methods do not motivate students' learning at the beginning of the course which would be the optimal point in time to build motivation. We are using learning contracts to make it explicit for students to acknowledge who is responsible and for what in the learning process.

The learning process can be seen as a transformation from one stage to another, so management of this transformation requires a good understanding of the two stages and also the transformation process itself. We have identified the relations between the goals of assessment and the assessment methods. [8] Then based on the goals of the course, it is possible to choose the most applicable assessment methods. Based on this thinking the assessment at a Product Development Project course was redesigned year 2009. The course is aimed for the students at the later phase of their Master studies, and its structure is based on lectures and on a large scale group assignment in which the aim is to plan a product development project on a given case. The students are evaluated by the final outcome of the group work. Each group has to evaluate how much information and/or value each group member has brought to the assignment, and then the assignment grading is weight based on this factor. Thus the students who actually influenced to the quality of the assignments final outcome get the better grading. They do not receive any extra points from the amount of work done or how much they can memorize different topics lectured at the course.

3.3 Meaningfulness phase 2010

This phase was about considering the role of a teacher more towards an enabler, a facilitator and a coach rather than being an expert on the content only. The main courses for 3rd and 4th year students cover product development processes, new product development, project management and product structuring tactics i.e. standardization, modularization and configurability. We noticed that teaching based on behavioural learning theory does not produce learning results needed and the teacher´s discomfort zone was visited many times. During this work we focused on two questions to gain more effectiveness: ***1) How the student can learn existing systemic knowledge*** and ***2) How the student is able to apply existing knowledge successfully?***

The learning approach is based on three assumptions. Firstly, ***the existing knowledge is like a network of connections between conceptual elements***. Secondly, ***systemic thinking is needed when designing large artefacts*** and thirdly, ***automated cognitive functions partly serve the problems solving tasks***. We use the term existing knowledge meaning such information that is commonly known in each engineering discipline.

We started by building a conceptual model that focuses on existing knowledge as a network of knowledge building, knowledge representation and procedural knowledge. The conceptual model was further developed based on the case findings [2]. The courses are developed based on this model. We achieved better learning result by teaching the subject as a model with visualized elements and relationships between the elements. A simulation game involves multiple memory types and facilitates personal knowledge integration when the learning process consists of doing, time for reflecting, discussion on the concepts and their meanings. When the students can apply knowledge within minutes based on the experiences, the neural connections strengthen. Time needs to be reserved also for metacognitive activities, such as making conscious choices on problem solving rather than using rote learning and procedural skills. We witnessed the learning to take place, and students who were able to apply the knowledge in new situations. This progress forced us to re-evaluate what knowledge was really relevant and useful for the students and for the industry. This time we had to stay in the discomfort zone of the expert. The work is still ongoing and the changes in the curriculum are gradually taking place. Some of the textbooks are considered now less important and textbooks with the latest developments are under work. Our understanding of the concept and contents of curriculum and curriculum planning has also increased a lot.

4 STUDENT EXPERIENCE AND INDUSTRY COLLABORATION

Over this period, we have made a systematic post course surveys on student experience so there is a reasonable knowledge about how students did feel these experiments. When preparing the very first simulation back in year 2000, the teachers were worried about using children's toys as the teaching material. As serious experts on this topic, no one wished to hear comments like "it was no teaching, but we were just playing with Lego building blocks". To avoid this, the original simulation was made extremely demanding in terms of technical complexity, schedule and criteria for success. In this sense, it was success as many students felt the simulation day very stressing and it was not uncommon to see adult students almost giving up or nearly crying! That was time when teachers considered themselves as experts and they had opinion that "learning must not to be fun at all". Very soon we realized that stressful atmosphere did make the simulation event memorable, but this happened on the expense of the understanding and remembering the actual learning content. The time schedule and criteria of success were eased and the long term learning results improved [11]. However, the technical complexity did remain and this simulation never became a real favourite of the students. When the next generation simulation was planned, the focus was placed on the learning aspects. Now the very basic Lego building blocks were used. This was the right direction as the focus of students was no longer distracted by the difficulty of assembling building blocks. This time the students encounter the challenges in applying and generating design knowledge, which was the purpose of the simulation. In addition, the attitudes towards the simulation day changed and instead it became the most celebrated event by the students in the course.

The gradual movement of the assessment from teachers to students own peer evaluation was popular from the very beginning. During the first years it was an optional alternative for traditional exam. Very few students chose the traditional exam even though the new, two-week long peer evaluation exam required a lot more effort. The industry collaboration serves the problem based learning. The group assignments are based on research projects with the companies and the latest development projects made by our researchers. Also the material available for students is actual design data from the companies excluding the sensitive information that could harm the company. In general, the students have appreciated the cases, such as speed boat and city bus. However, one exception was maybe the case when students designed a container ship concept using actual design data. This time it took quite an effort for the students to read through the material available.

5 CONCLUSIONS AND DISCUSSION

Within hindsight, the period of ten years of teaching product development seems like a spiral that has reached all of the areas of teaching, and finally reached the knowledge itself and its ways of presentation. In this case, development sequence appears to be logical and the focus on developing is expected to stay in this area. The state-of-art in our teaching consists of the following aspects:

1) Constructivist approach. We build on top of the students' existing knowledge, as the learning is creating connections between existing elements and new elements. If the learning topic is new and not in the zone of students proximal development we arrange particular experience for the students using games, analogies or simulations.

2) Experience based learning and learning by doing. The practical experiences incorporate students' all senses and emotional aspects when they are successful. The learning can be increased by having repetition in the simulation game. If the experience based learning is designed in good fashion there are steps embedded for reflection and building further the concepts and conceptual models. Also, it encourages metacognitive activities such as evaluation and analysis of the simulation results and models, and how successfully the knowledge was applied.

3) The conceptual models and cause-effect models are representations of systemic thinking. The connections and elements are not distinguished as separate "islands" rather than parts of the whole. The whole can be learned step-by-step bearing in mind the students zone of proximal development.

4) Change in the division of work. The learning takes place also in the evaluation. When the students are also evaluating the work of others and exam answers they can learn from that. In order to be able

to evaluate something, one has to clarify what are the criteria for good work and how to identify those from own work and from the others work. This also reduces the resources required for education.
5) Problem based learning for new insight and well functioning team work. The students work as a team and practice the use set of tools. Some of the feedbacks received from the students now situated in industry are very promising. The problem based learning increased their self esteem and "can do" attitude.
6) Motivation, rewarding and leadership based on the sustainable values. The student is motivated when the learning topic has some meaning and purpose from the student's viewpoint. If the topic is not within the zone of proximal development this is difficult to achieve. Rewarding can take many forms as some students prefer numeric feedback and the other students like to elaborate and discuss further on.
Currently, it is not easy to see whether there are more steps in the teaching development, or is the next step in the development to start the sequence again on the higher level of expertise.

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