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DESIGN REASONING PATTERNS IN NPD EDUCATION DESIGN

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ABSTRACT
Our motivation is to introduce how design reasoning patterns are used in the Integrated Product and Product Design study module design. We use three education design questions to demonstrate what the design reasoning patterns are. The first question focuses on the interplay of subject matter and pedagogical content knowledge. The second question focuses how new scientific findings in research projects impact on course contents. The third question focuses on the many aspects and stakeholders making decisions on the curriculum. This research follows educational design research methodology. We use data from our six teaching development projects, most of them reported in earlier E&PDE conferences, the reports and related research. The map is updated based on the research project results, case summaries from the IPPD courses from our experiments and observations during the years 1995-2014.

The design reasoning patterns show how the simulation game creates common point of reference to the students and to the teacher. It is an example how increased pedagogical content knowledge effects on student learning and on teaching effort. For the second question we are able to find reasoning pattern that shows the "Teacher as researcher" –approach is working and how the latest research results can be used quickly in education. The design reasoning pattern for the third question reveals that the background and work life experience of the professor and his predecessors played a key role on the curriculum design and that there are many stakeholders with different needs having effect on the curriculum design.

Our experience is that design reasoning patterns are a useful tool to make subject matter knowledge and pedagogical content knowledge explicit and develop course content and implementation. The map creates common ground for people from different functional areas of university organization to develop curriculum together.

Keywords: Design reasoning pattern, cause-effect map, curriculum design, course design, teacher knowledge domains, subject matter knowledge, pedagogical content knowledge

1 MOTIVATION

Could the course development and curriculum design be more efficient, less time consuming and result in better performance in learning with less effort from student and from teacher point of view? The goal of this paper is to show what design reasoning patterns are and how these patterns, visualized as a map, ease the curriculum development, course development and implementation.

Engineers, designers and project teams are able to create systems and artefacts more and more efficiently. Global companies use platform organizations and module development teams to support efficient design by re-use. The organizational aspect and the components developed earlier are required but this does not suffice. Efficient design by re-use requires understanding of design reasoning of the originating team by the re-using team. This is not currently supported by PDM/PLM systems [1]. Typically some changes in design are needed to fulfil the project goals. Therefore it is very important to know the originating team assumptions and constraints for the re-usable component. Otherwise too much redesign is needed thus creating waste work and losing the efficiency. The role of explicit design reasoning patterns and the routines to capture and share them is the key to efficient product development. The research in Japan [2] and our recent cases [3] in companies' highlights how it plays major role for achieving the efficiency and faster time to profit.

We have used design reasoning mapping successfully in multiple new product development cases in industry. Curriculum design, course design and implementation with reasonable development steps and change control is a similar design challenge for teachers as the creation of technical system for engineering team. Now we apply the same approach in education design context and use concrete examples in the Integrated Product and Production Design education design.

In this research the **design reasoning pattern** refers to knowledge on the reasons why the product is as it is. This is typically tacit knowledge by nature. For example we could get all the design data from VAG group and investigate the product architecture and structure of Audi A6. We can see all the components and sub-assemblies in the 3D-CAD but the documentation explaining why the architecture is such, why those particular technologies and components were chosen is missing. To our knowledge the current design and engineering processes in industry require documents for the manufacturing as the outcome. The path how these solutions were conceived and chosen is not requested. The information why the designers and engineers ended up with these particular choices is not required nor managed. The quality of the design can be improved and the design management can be more effective with the visualized design reasoning patterns.

2 RESEARCH AND EDUCATION CONTEXT

IPPD Research team works very closely with the industry and most of the research is done with companies. This research is an exception and it is done together with the university students. Our education context is higher education, from first year to fourth year students aiming for Master of Science in product development. The IPPD study module consists of four courses and the basic information is presented in Table 1.

Table 1. The IPPD study module courses

					Learning event types		
Course	Semester	N:o students	Credit points	Planned learning events	Lectures %	Personal work %	Team-work %
Product Development	2	100	4	13	50	50	0
Modularization	6	50-60	5	12	95	0	5
NPD Project management	6	30-40	5	7	10	10-20	70-80
CDIO (Candidate level)	7	30-40	4	4	10	10-20	70-80

Table 1 covers the courses within the scope of this study. One planned learning event can be lecture, facilitated group work or e.g. simulation game session. The learning events have a planned sequence. The percentages show the emphasis between different learning event types.

3 RESEARCH APPROACH AND STEPS

This research follows educational design research methodology (EDRM) [4]. We use data from our six teaching development projects, most of them reported in earlier E&PDE conferences, the reports and related research. The map is updated based on the research project results, case summaries from the IPPD courses from our experiments and observations during the years 1995-2014. We also use research on teacher knowledge domains and university wide study on the current state and challenges in university education. This data is also integrated to the map.

We use following steps for this modelling activity: 1) Identify elements based on the final deliverable. 2) Go to the detail level needed to be able to map out the dependencies. 3) Remove hierarchy to simplify the model. The model is based on cause-effect connections, not based on hierarchy and classification. 4) Identify dependencies between elements. 5) Validate the map and make corrections. 6) Identify design reasoning patterns.

In this kind of work the challenge is to find out what is the appropriate level of detail. If the elements are on too abstract level they look black boxes to us. The problem is that we don't know what happens

inside the black box. If the elements are on too detail level the validation is very laborious. It is more difficult to find out the relevant elements for the design reasoning patterns with too many details.
The modelling is also a learning activity for our research team. Some of the decisions regarding course development and study module development have been conscious and some based on tacit knowledge. According to Putnam et al. [5], the subject matter knowledge consists of the course content and subject matter i.e. what to teach. The pedagogical content knowledge consists of methods, tools, representations, stories, metaphors, analogies etc. on how to teach certain subject matter for certain students in particular learning event [6].

4 IPPD EDUCATION DESIGN REASONING PATTERNS

The modelling results in lot of elements and it requires printed A0-size map to be able to see and read the elements. The map size forced us to present only some of the design reasoning patterns here. The map is done with CMAP-tool and is available in Research Gate [7]. We use three education design questions to fulfil our goals and to demonstrate what the design reasoning patterns could be. First question focuses on the interplay of subject matter and pedagogical content knowledge. The second question focuses how new scientific findings in research projects impact on course contents. The third question focuses on the many aspects and stakeholders making decisions on the curriculum. The **text is on bold** when it is part of the design reasoning pattern and visible in the map.

4.1 Why to use simulation games during early phases of the course?

This is an example of the subject matter and pedagogical interplay. **Problem based learning was familiar approach** for the teachers since 1994 and different kind of concrete design tasks were used as simulations for the students in other courses to some extent. The first NPD simulation game experiences were from industry during 2000-2002[8, 9]. The learning results were promising [10] and the same simulation was used also for the students in Modularisation course. It was used in second last lecture. The students learned partially the design re-use phenomena but most of the focus was in building blocks and in the details of the construction kit. It gave the basic idea of platforms but it **was not integrated** to the subject matter. After some years when the research group had acquired **better understanding on the Module Systems**, the simulation was reinvented with the support of external simulation game experts. It is based on **simple construction kit**, easier to assemble and the **Kolb's learning circle [11]** with concept mapping was integrated to the simulation game. The learning results were much improved due to the **constructivist** approach **with concept mapping** and **hands on learning**. During 2013 the subject matter **sequence** was altered. The first lecture is introduction to Module Systems and the second learning event is implemented with simulation game.
The student background and experience **heterogeneity** has increased during 2002-2014. There are more and more students that **lack concrete experience on technical systems**, how they work and how they are repaired. How could they have any **reasonable mental models to** learn the challenges in designing such systems? The simulation game enables **common point of reference** to the students and to the teacher. Later during the course learning events the teacher can refer any occasion during the simulation game, reminding of the concrete challenge or situation **and interweave it to the subject matter** at hand, such as how to design interfaces for the Module System for module interchangeability. The recent learning results have even improved due to these changes. This shows how increased pedagogical content knowledge can reduce teacher work effort and enhance student learning.
Product Development course is an introduction to technical systems, different development processes and NPD project organisations. During 2013 and 2014 new simulation game was used. The key subject matter is to highlight how the number of project participants have an effect on project problem solving ability, communication ability and to the project schedule. This simulation is used after the introduction lecture. The students are divided into three groups, 10-person, 20-person and 70-person group. They are given the same design task and 15 minutes to create the solution with basic building blocks. After this we facilitate pair discussions on what was the challenge. The findings are written on the board for each group. In this point the teacher is able to assess how well the students learned the subject matter and can elaborate on the topic if needed.
Based on the student findings the teacher explains **how and why the simulation is done again**. This time there are **many changes** such as **smaller groups**, the design task is divided into **smaller steps**, concepting phase, development phase and integration phase. The most **viable concepts are chosen**

and **interface and layout drawings are documented** on the board. **Team leaders are chosen** and **communication practices** are agreed. Then the simulation is done again. This time the result is much better, the **steps are visible** and most of the students had worthwhile contribution to the design task. The reasoning pattern for this implementation is similar to the Modularisation; the **heterogeneity, lack of concrete experience on technical systems and lack of project work experience.** They **have not been in NPD project** so they cannot imagine the effect of number of people. In this case the simulation enables **common point of reference** to the students and to the teacher and it **provides motivation to study** the rest of IPPD study module.

4.2 How the key subject matter is chosen for NPD project management course?

In the 90's, NPD Project management was based on Critical Path Management and learning the PERT. This was mainly due to the work life experience of the professor in charge. The company specific project management manual was the starting point and one tool was covered in one lecture. The educational goals were different from current situation. Nowadays we also have more expansive and relevant set of literature, study books, journal publications and research results on new product development project management. **Ambition has also grown during the years and the needs from the industry** and from the academy, too.

The changes were based on **problem based learning (PBL)** and the project cases varied from container ships to buses and bicycles. The goal is to create plan and schedule for **new city bus and the production system**. We encourage the students to take **responsibility of the overall success** rather than optimise own grade only. The team that presents the most competitive offering, wins and they get raise on the final grade. The **success criteria's are credibility of the project plan, delivery time, cost of the bus and fulfilling the technical requirements**.

During 2010 our **research project** in this field had good **results** from the industry and software tool was prepared to manage project delivery dependencies. Gantt-chart software is used and it was capable of creating schedules. It is focused on tasks and resource management but it is poor on modelling **how new knowledge is emerging during the development project**. On year 2012 the tool, especially designed to model and manage how new knowledge is created, was taken in use. At the same time the course content was changed to emphasise "white box" project management; manage the project based on deliverables, deliverable interdependencies and tasks rather than task management and reporting that is more like "black box" project management.

The project teams had typically **90-130 tasks** in their project plans during 2007-2012 and the teams' reported some or major problems in managing the dependencies with MS Project. By nature the tool does not support iteration that often takes place in these NPD projects. Year 2013 one team had over **1100 tasks** in their plan yet reporting it was easy to manage changes, iteration, dependencies and critical path with the tool combination. Year 2014 the best team had gone **over 2000 tasks** in the Gantt-chart without problems. This is **major leap for the project management efficiency and accuracy**.

Since 2009 the project team had to make agreement on their **operative practises**. The teams created such a document as it was requested but it had no impact on their actual working habits. On year 2014 the fifth learning event on the course is dedicated on operative routines and learning in the projects. This time the project teams were using facilitation method and templates created by Kopra [12]. Each team was able to identify what project routines to improve and they also created practical actions for the next week to improve the chosen routines.

The design reasoning patterns in this case originate partly from the **new subject matter knowledge found and created by the research group**. In our case we have **highly integrated education and research team** where the same persons do both research and education and the "teacher as researcher"-approach [13] is working well. The **competition approach is used** as this **is the reality in projecting business**, only the best gets the deal.

4.3 Why the IPPD Study Module consists of these courses with these subject matters?

The modelling is based on Culture Historic Activity Theory [14] and when applied with organisations and institutes we need to consider what has happened earlier to understand what the situation right now is. We continued expanding the model by considering all influencing activity systems to the curriculum design. In this paper we elaborate the key activity systems starting from Ministry of

Education to the student and course level activity system. The decision making takes place in these activity systems based on different goals and policies. The decisions made on Ministry has effect on university, faculty, laboratory, professor and researcher via several routes.

The Ministry of Education and Culture provides certain amount of money within education policy agreed in the parliament. The policy guides students to graduate within 4 years, sets constraint on how many **starting places are opened** per university and curriculum etc. University gets funding mainly based on number of graduates thus setting motivation for the activity systems beneath to adjust the goals and criteria for passing the course accordingly. On university level there are **many faculties with own curriculum consisting of partly same study modules or courses**. This creates interdependencies between the courses and also between the implementations on different years. Different faculties **change their curriculum, study modules and courses on different intervals** and the change control for single course is difficult.

On research group level activity system there is control from the above mentioned activity systems. The **industry requires competent and capable students** and this message is conveyed from university board level to faculties and laboratories. The culture and goals in these activity systems Roth et al. [14] have big influence on the course development and on the study module development and implementation. The course development and study module **development is affected by the valuation and contribution** from the professor and from the research group members. The IPPD group has **direct contacts with industry people** and open forum for industry and researchers to discuss on the product development issues.

According to Kujansuu [15] in worst case the successes in education development are not discussed at all in personal performance review with the professor. In some cases there was no time allocated or reserved on course development. On teacher activity system the findings were much more inspiring by Kujansuu [15]. The teachers were enjoying the academic freedom to choose their own focus, they had **strong personal motivation** to develop the course and to be **experts in the subject matter and in the pedagogical content knowledge**.

The design reasoning patterns show that there are many aspects on curriculum design and many stakeholders with different needs having effect on the curriculum. The curriculum design appears to be very iterative and consists of lot of **interdependencies between different decisions** needed. In addition the university as an **organisation suffers from conflicting decisions and lack of decisions** on different organisation levels. During the modelling we realised that **the background and work life experience of the professor and his predecessors played a key role on the curriculum, courses, course contents and subject matters.**

5 CONCLUSIONS

The design reasoning patterns provide answer to the first question by visualizing how the simulation game creates common point of reference to the students and to the teacher as well as interweaves the engineering challenges during the learning event to the subject matter. It is an example how increased pedagogical content knowledge effects on student learning and on teaching effort. For the second question we are able to find reasoning pattern that shows the "Teacher as researcher" –approach is working. The latest research results can be used quickly in education because of the knowledge is transferred within the highly integrated education and research team. The design reasoning pattern for the third question reveals that the background and work life experience of the professor and his predecessors played a key role on the curriculum and that there are many stakeholders with different needs having effect on the curriculum design.

Our experience is that design reasoning patterns are a useful tool to make pedagogical content knowledge explicit and develop course content and implementation. The map creates common ground for people from different functional areas of university organization to develop curriculum together.

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