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Dealing with complex and ill-structured problems: results of a Plan-Do-Check-Act experiment in a business engineering semester

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ABSTRACT

Challenged by increased globalisation and fast technological development, we carried out an experiment in the third semester of a global business engineering programme aimed at identifying conditions for training student in dealing with complex and ill-structured problems of forming a new business. As this includes a fuzzy front end, learning cannot be measured in traditional, quantitative terms; therefore, we have explored the use of reflection to convert tacit knowledge to explicit knowledge. The experiment adopted a Plan-Do-Check-Act approach and concluded with developing a plan for new learning initiatives in the subsequent year's semester. The findings conclude that (1) problem-based learning develops more competencies than ordinarily measured at the examination, especially, the social/communication and personal competencies are developed; (2) students are capable of dealing with a complex and ambiguous problem, if properly guided. Four conditions were identified; (3) most students are not conscious of their learning, but are able to reflect if properly encouraged; and (4) improving engineering education should be considered as an organisational learning process.

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1. Introduction

Increased globalisation and fast technological development have challenged many industrial companies. They have to operate in a dynamic world with many unforeseeable events, and engineering and business solutions should be developed that integrate different disciplines and requests from stakeholders. The nature of these challenges has been spelt out by a number of studies, for example, the Manufuture report 'A Vision for 2020'.

The industrial challenges have been reflected in a number of initiatives to define desired attributes of an engineer, for example, 'The Engineer of 2020' by the National Academy of Engineering, 2004, and the Graduate Attribute Profile of an Engineer, stated in the so-called Washington Accord by the International Engineering Alliance in 2012. National engineering associations in many countries have adopted these desired attributes.

In this article, we shall in particular be concerned with the challenge of engineering students learning to deal with complex and ill-structured problems. As pointed out by Zhou (2012), engineering education needs to foster creative students to face the challenges of complex engineering work.

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Through an experiment in a whole semester of a business engineering programme using problem-based learning (PBL), we studied under which conditions it is possible for students to successfully learn to develop holistic solutions to a complex and ill-structured problem.

However, as we confront students with such open-ended problems and ask them to be creative, their learning will be of a different nature than can be measured by an ordinary examination. We wanted to seek new ways of measuring what students have learnt, for example, asking them to reflect individually and collectively on their results and their learning process.

The remainder of this section provides a background for our experiment by a literature review. Section 2 outlines the research method, questions and background, and Section 3 describes the design of the experiment. The findings are presented and discussed in Section 4, and Section 5 holds conclusions and implications.

1.1. Background – PBL

Not only are universities and engineering schools cognizant of a broad spectrum of desired attributes of an engineer, they have also implemented numerous initiatives aimed to develop competencies relevant for the professional engineer. Foremost is the PBL approach. It builds on experiential learning and is especially focused on learning problem-solving skills such as analysis, scoping and formulation of open-ended, complex problems, as well as developing a comprehensive solution (Barrows 1985, 2000). A large number of successful implementation of the PBL approach is reported in the literature, for example, de Graaff and Kolmos (2007) and Lehmann et al. (2008). This also holds for the area of industrial engineering and management, for example, Yeo (2007), Kolmos, Flemming, and Krogh (2004) and Steffen, May, and Deuse (2012).

Zhou (2012) emphasises the importance of fostering creative engineers as a means of coping with the complexity of engineering practice. However, he also points to barriers to creativity in engineering education. Badran (2007) argues along the same lines and proposes to nominate an engineering creativity facilitator to inspire students in their projects.

Richter and Paretti (2009) review more than 20 articles describing interdisciplinary projects and courses. They point to some key barriers to successful collaboration: a lack of knowledge about the information needs of others; a lack of integrative knowledge and abilities within and across disciplines, and cultural expectations varying with individual and discipline. This finding was substantiated by their own case study.

The complex nature of engineering design stimulated Harrison, MacPherson, and Williams (2007) to develop a series of interdisciplinary design courses. This led students to appreciate other engineering disciplines, links between engineering design and economic viability, and the relevance of attending to non-technical aspects. Team leadership turned out to play an important role for their achievement.

In a university entrepreneurship programme, Crawford, Broer, and Bastiaansen (2006) let students in teams experience the ‘fuzzy’ front end of starting a new business. They found that it was important that faculty members serving as facilitators had industrial experience, for instance, when they had to encourage students to make initial assumptions on the basis of intuition and scarce knowledge.

Puente, Van Eijck, and Jochems (2015) report on a development programme of introducing teachers and supervisors to design-based learning (DBL) and show that the programme was instrumental in increasing the application of DBL. They identify five dimensions of DBL to be considered: project characteristic, design elements, role of the teacher, assessment, and social context.

An issue in applying PBL is to decide on the level of uncertainty and complexity of a project task or problem. Gattie et al. (2011) present a theoretical solution space of socio-technical problems as a function of problem domain and problem-solving methodology. Based on the problem domain that reaches from well-understood relationships to complex and vaguely defined relationships, the paper proposes problem-solving methods that reach from reductive analysis to holistic design.

We are particularly interested in the very open-ended problems with many unknowns and aspects to be integrated. As pointed out by Puente, Van Eijck, and Jochems (2015), further research is recommended into supporting teachers to develop open-ended and multi-disciplinary activities. There is a need to better understand which factors may facilitate a positive learning process for students.

1.2. Assessment and reflection

Biggs and Tang (2007) have introduced a model of Constructive Alignment in which the desired learning outcome, the learning environment and the examination needs to be aligned. When we change the intended learning outcome to include a capability to deal with complex and ill-structured problems, and design a learning environment to rest on a PBL approach, we should also be prepared to develop the method of assessing the acquired competencies accordingly.

A number of new assessment methods have been introduced to better measure the increased competencies. Puente, Van Eijck, and Jochems (2015) use a broad spectrum of evaluation methods through the semester and after. In regular engineering courses with many students, O'Moore and Baldock (2007) demonstrate that peer assessment learning sessions provide useful feedback and help correct individual misconceptions during the course. Willey and Gardner (2010) have used an IT system for self and peer assessment in a fundamental design course, and report that students effectively improved their understanding and ability.

An important part of experiential learning is the stage of reflection (Boud, Keogh, and Walker 1985; Moon 1999). Without reflection, there is no effective learning possible, neither with respect to technical attributes nor in the context of personal competencies such as 'learning to learn'. To enhance an intensive reflection, a popular didactic element is to ask students prepare a learning log (McCrindle and Christensen 1995; Nueckles, Huebner, and Renkl 2009). Another promising method to reflect learning is the dialogue (Bohm 1996; Isaacs 1999). In terms of knowledge management, the dialogue is an important method to communicate tacit knowledge (Senge 2006) and to derive new knowledge based on an open and unbiased communication process exchanging opinions and thoughts.

Most of the articles on assessment focus on technical and professional learning outcomes in a traditional sense. However, Choulier, Picard, and Weite (2007) address the tacit knowledge acquired when dealing with a multi-disciplinary and innovative design problem. They have introduced reflective practice in a design course and conclude that it stimulates the conscious use of tools in the design process and acquisition of procedure-oriented knowledge.

We find that there is a need for further studies in this direction. To this end, we shall draw on the Kolb model (1984) and Nonaka and Takeushi's model (1995). The Kolb model of experiential learning can be described as 'learning by doing' or 'learning by experience' (Alstrup and Kofoed 1997; Gibbs 1988; Kolb 1984). The model includes a circular process of interchanging deductive and inductive learning and thus combining theory and practice. The learning cycle may help identify two essential ways of acquiring knowledge, that is, of learning:

- *Reflection*. To derive knowledge from practical experience requires a systematic reflection, for example, to seek patterns of observations that presupposes some extent of abstract thinking.
- *Experimentation*. Another way of learning implies defining new theories and models that are substantiated through experimentation.

When dealing with complex and ill-structured problems, much of what is learnt cannot be expressed in quantitative terms. Nonaka and Takeushi (1995) have introduced a distinction between tacit and explicit knowledge. This led them to introduce four types of learning (knowledge conversions), the so-called SECI model:

- Tacit to Tacit (Socialisation). This dimension explains social interaction as sharing tacit knowledge; for example, a student group's meetings with their advisor or an internal discussion in the group.

- Tacit to Explicit (Externalisation). This takes place when a student group develops a model of their perception of their project task, to allow for a more in-depth discussion.
- Explicit to Explicit (Combination). This represents the traditional working mode of analysis and synthesis in which various explicit data and models are brought together, combined, edited or processed to form new knowledge.
- Explicit to Tacit (Internalisation). This dimension underlines that explicit knowledge, in order to become useful for an individual, must be accepted and transformed into personal skills. Internalisation is also a process of continuous individual and collective reflection.

The SECI model underlines the important role of tacit knowledge in engineering education and the challenge to explore how to stimulate the three types of knowledge creation involving tacit knowledge. This suggests that great care should be taken to make use of the tacit knowledge in engineering education. For example, to involve all group members in scoping and defining their project task, and to use all senses when analysing and trying to understand the results.

Hence, when we focus on students' learning of the complex and open-ended front end of a design problem or a new business case, there is a need for a better understanding of how reflection among students may stimulate their learning by making their tacit knowledge more explicit, and how reflection may help evidence learning.

2. Research method, hypotheses and background

2.1. A Plan-Do-Check-Act approach

When planning to introduce changes in an existing education, an organisational development process approach is useful, because it may take several semesters to introduce and implement a major change. Furthermore, education development most often implies major changes in faculty attitudes and behaviour, and many interested parties have a stake in the education programme.

To this end, we have adopted the Plan-Do-Check-Act (PDCA) method. PDCA is an iterative four-step management method used for continuous improvement of processes (Shewhart and Deming 1939; Shewhart 1980) and for learning about the process (Hempen 2014). It is based on the scientific method described by Bacon (1620) in 'Novum Organum', which includes 'hypothesis,' 'experiment' and 'evaluation'. To achieve continuous improvement, PDCA needs to be used in iterations. The four steps consist of:

- Plan: Define an experiment and a hypothesis about the results (expected output). Do also decide on the data that needs to be collected during the experiment to test the hypothesis.
- Do: Implement the plan, that is, conduct the experiment and collect all necessary data.
- Check: Study the results, that is, to analyse and discuss the data and observations (falsify or verify the hypothesis).
- Act: Reflect on what has been learnt by testing the hypothesis and request actions aligned with the learning results. Initialise the next logical experiment for further improvement.

Once a hypothesis is supported or not supported, the cycle will be executed again to improve a process towards an ideal state (Rother 2010). The PDCA approach, which became popular by Deming in the domain of quality control (Deming 1986), can be applied to all sorts of projects or improvement activities (Rother 2010). It also has many elements in common with the experiential learning approach by Kolb (Hempen et al. 2010).

Experiments can be divided into different types, such as discovering experiments and experiments to test hypotheses for improvement (Alberts and Hayes 2003; Hempen 2014). In most cases, the improvement activities start with discovering experiments to learn more about the system or process that needs to be improved. As this is also the case in the PDCA experiment presented in this article, we decided to start formulating research questions instead of hypothesis.

2.2. Research questions – starting point for the PDCA experiment

Challenged by the industrial requirements of being able to operate in a complex and dynamic world, originally we wanted to explore how far it was possible to come in implementing the potential of experiential learning. The third semester of the global business engineering (GBE) programme at Aalborg University was selected.

Aimed at both courses and semester project and yet accepting the barriers of getting all involved faculty on board, the experiment focused on dealing with the complex and fuzzy front end of developing a new business.

Based on initial observations and interviews of students, we realised that they benefitted from reflecting on what they had experienced and learnt. This led us to explore reflection as part of a learning process and to propose evaluation forms that would supplement traditional, result-oriented assessments.

We were also interested in measuring how experiential learning increases students' competencies. We have formulated three research questions allowing for a broader discussion of the results:

RQ1: Which competencies do experiential learning develop?
RQ2: Which conditions may facilitate a positive learning process for students confronted with a complex and ill-structured project?
RQ3: How can reflection among students stimulate their learning and contribute to evidence-increased competencies?

2.3. The third semester of GBE – background for the PDCA experiment

The GBE programme is a BSc Engineering programme with about 40 students and feeds three Master's programmes. It is a 10-year-old programme and has functioned well so far with a challenging focus and broad approach. It has been well received by industry and by students. All programmes at the Aalborg University are based on PBL (Kolmos, Flemming, and Krogh 2004). In each semester, the education is divided evenly between a semester group project that is based on a practical problem and a number of courses taught in a traditional way. Each semester has a theme that serves as a guide for defining the project and relevant courses. The themes of semesters for the GBE programme are as follows:

- 1+2: Introduction to project work, process mapping and analysis, operations management and business processes
- 3: Marketing, product, production systems and finance
- 4: Operation systems
- 5: Supply chain management
- 6: Globalisation
- 7: Thesis.

With the theme of the third semester being integration of marketing, product development, production systems design and finance, the semester offers an excellent opportunity to explore new learning methods addressing complex and open problems. Therefore, we focus on the third semester of the GBE programme.

The study programme for the third semester includes three comprehensive courses, each counting five European credit transfer system (ECTS) and concluding with an individual examination. The courses are:

- Marketing and finance
- Product development and production preparation
- Statistical methods for production and quality

The semester project is carried out in groups of five to seven students and counts a weight of 15 ECTS. Each group prepares a written report that is presented and discussed at a final examination in which individual grades are given. The subject of the semester project should give the student an opportunity to deal with market analysis, product development, production systems design and finance, and it varies from year to year. In the fall of 2013, the semester project was to create a new business for a new product related to the LEGO® brand.

3. Design and description of the PDCA experiment

3.1. PDCA-Phase 1: plan

Based on the three research questions presented above, an action research plan was prepared and implemented for the third semester of the GBE programme in the fall 2013, cf. Reason and Bradbury (2008). The aim was to carry out an experiment on introducing new experiential learning methods in a PBL setting, inspired by an effort in the European Academy of Industrial Management (AIM) to promote experiential learning and PBL in engineering management programmes (www.europe-aim.eu).

First, an EL-based introduction to the semester project was considered relevant for the aim to develop the capability of dealing with complex and open problems. Second, integrating more inductive learning methods into courses in two subject areas offered an opportunity to address all types of competencies. A detailed description of the changes is presented in the second phase 'Do'.

To measure the effect of the experiment, it was decided to use a mixture of quantitative and qualitative as well as subjective and objective methods in order to achieve a broad understanding of the learning effects. A questionnaire was prepared and used after the initial three-day workshop and after the finance game with a response rate of, respectively, 37% and 64%. Also, a rather elaborate questionnaire was prepared after the semester to measure the overall effect, especially on competencies – with a response rate of 44%. In addition, a senior faculty member observed the introductory workshop and finance game, thus supplementing the questionnaires. Interviews were carried out of students from the previous year's semester, the present year's students during the introductory workshop and finance game, and after the semester. Also, the semester and project coordinator, teachers and project supervisors were interviewed after the semester. In the course of the interview, the semester and project coordinator formulated a plan for the next semester's improvements that supported the view of educational improvements as an organisational learning process, which should be based on PDCA cycles.

3.2. PDCA-Phase 2: do

A two-day workshop with participation of faculty members was held in April 2013 to discuss additional experiential learning methods to be introduced in the fall 2013. As a first result of the workshop, inductive teaching methods were implemented in two courses:

- To introduce the finance course by a business game. A successful game (Income–Outcome) was run early in the semester as a means of obtaining hands-on experience of basic concepts, such as income statement, balance sheet and their interconnections. The game was played in two rounds for a whole day. Each round included six groups (companies) with four to five members.
- To use inductive methods in the marketing course, so to speak 'to make students hungry for knowledge and experience'. Each of the five mornings of the course, a topic related to preparing

a marketing plan was selected for discussion. Instead of lectures, the students were asked to visit a number of internet presentations on developing a marketing strategy and a marketing plan, as well as journal papers and book chapters. The students were asked to apply their findings to their semester project.

As a second result, the semester project was changed:

- To let the students experience integration of marketing, product development, production systems design and finance through a three-day TURBO introductory workshop (fast workshop including all topics) on developing a new business at the very beginning of the semester. The project task was to develop a new business model for selling specific LEGO® minifigures. Very little information was available in the beginning, so the facilitator guided the students through a series of small sessions discussing 'what do we know' and 'what do we not know', as a means of letting the students feel comfortable about making assumptions in face of uncertainties and complexities. On the third day, the student groups had developed different business models, each with specific features, including key customers, expected sales volume, facility layout, scalability, financial budgets, risks and potentials.

Although half of the students' time is devoted to their group project, pointing to project-based learning, most of the experiment focused on PBL, as evidenced in the marketing and finance course and the TURBO introductory workshop. Therefore, we shall think of PBL as PBL in which project-based learning is embedded.

4. Findings and discussion of the PDCA experiment

4.1. PDCA-Phase 3: check

4.1.1. General findings

At the interview with three students after the semester, they found the semester quite extensive because of the open project task, the four different subjects to be addressed, and the many detailed decisions required. However, they learned the hard way to balance the various demands and to cope with an ambiguous and complex task. In fact, one student mentioned that the ability to cope with lack of information was an eye-opener. As to the group dynamics of the project groups, the interviewed students represented different experiences. In one group, they had joint discussions about all four subjects and had initially several brainstorming sessions. In another group, apparently everybody wanted to become project manager with the consequence that they early on specialised in one or two subjects. In a third group, two members played an integrating role, seeking coherence of solution, in addition to working in one or two areas. The students voiced the challenge to align different levels of ambition in the group from an intention to be the best to an interest in minimising the necessary effort in order just to pass.

The questionnaire sent out at the end of the semester included a question of what surprised the most, that is, an 'Aha' experience. The most predominant response pointed to the finance game, for example:

- 'The income–outcome game showing the effects of liquidity really was an eye-opener.'
- 'How much finance affects the overall decisions.'

Also, the new teaching approach in the marketing approach was mentioned, for example, 'that the learning in the marketing lectures was our own responsibility'.

The students were asked to describe their overall impression from the semester. Most respondents found that the semester had been good, and some stressed that the courses supported the semester project. They found the semester project very challenging and time demanding. Some students would have liked the project to be more limited in scope. A report has been prepared offering detailed observations and comments as well as results from the questionnaires (Riis 2014).

4.1.2. Data about competence development

With the industrial challenge of developing a broad spectrum of competencies in mind, we included in the questionnaire a set of questions about the development of four types of competencies: professional/methodological competencies, social/communication competencies, personal competencies, activity/implementation competencies (Erpenbeck and Rosenstiel 2007; Steffen, May, and Deuse 2012).

The response to the increase of professional/methodological competencies is summarised in Figure 1.

As examples, students specified their response as follows:

- 'By getting an insight into how many functions are interrelated, I have become better at solving problems.'
- 'I have learned different approaches to engage in project handling.'
- 'I know how to develop a product, sell it to customers, produce and finance it.'
- 'I think that I am more capable of identifying and analysing the root of problems by applying the knowledge of several organisational functions.'

The response to the increase of social/communication competencies is summarised in Figure 2.
As examples, students specified their response as follows:

- 'Since we were a large group (seven persons), we had to resolve differences and overcome problems quickly to cooperate with each other.'
- 'I am able to learn from the other group members and compare myself to them.'
- 'I work better in groups and can identify who is "capable" and who is not.'
- 'I am now more capable of working together with group members on more complicated tasks, whereas I previously preferred to work alone.'

The response to the increase of personal competencies is summarised in Figure 3.
As examples, students specified their response as follows:

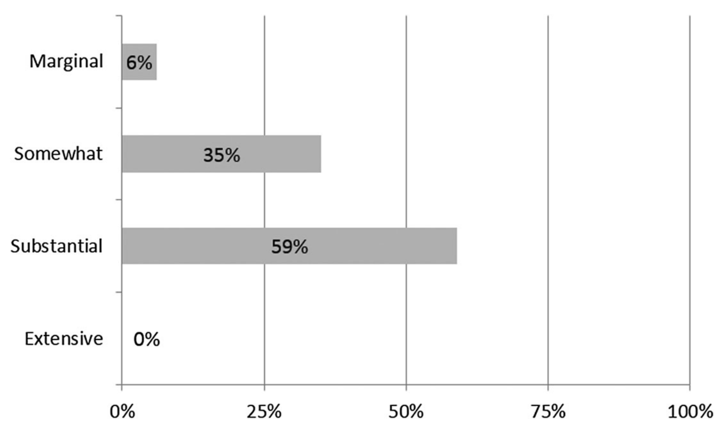

Figure 1. Increase of professional/methodological competencies.

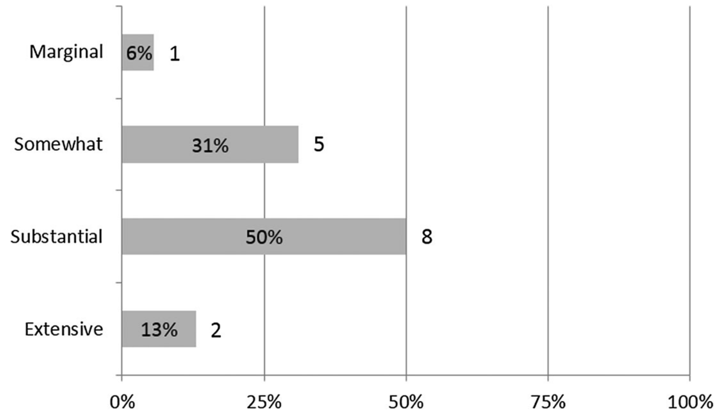

Figure 2. Increase of social/communication competencies.

- 'I can identify my own competencies and what I miss.'
- 'I know my strong sides and what I need to work on.'
- 'I am able to deal with large amounts of readings and project-based tasks. I am able to apply theory in practice. I can distinguish between need to know and good to know.'

The response to the increase of activity/implementation competencies is summarised in Figure 4. As examples, students specified their response as follows:

- 'I have increased my capability to act in a self-organised way; but I am not sure if it was the courses or myself that taught me the capability to do so.'
- 'I have learned to use competencies of others.'
- 'I can implement my knowledge to the project.'

The questionnaire indicates that students find that their competencies have been increased. The personal competencies have received the highest score, and also their social/communication

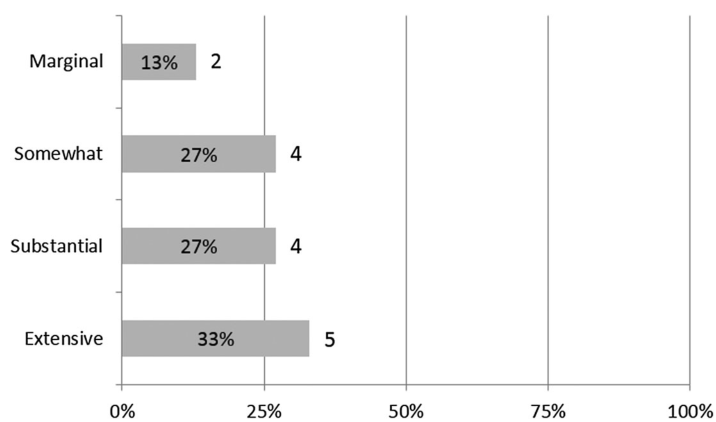

Figure 3. Increase of personal competencies.

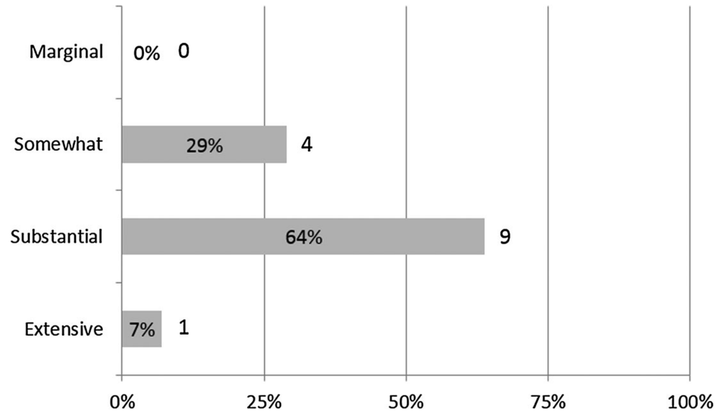

Figure 4. Increase of activity/implementation competencies.

competencies have been developed significantly. In the next section, we will discuss the findings of the experiment by relating them to the three research questions.

4.1.3. Discussion of RQ1: PBL and competence development

There seems to be an interesting interdependency between the four types of competencies when PBL is applied. By nature of the task to develop a solution to a complex problem, the activity/implementation competencies are developed. In particular, the capability to synthesise different ideas and perspectives are important. On the other hand, there is ordinarily only a limited opportunity to be engaged in realising a solution. The social/communication competencies are developed by conducting the semester project in a group. As it clearly surfaced during the interviews with students, a student group will have to resolve disputes and conflicts; otherwise, they will not be able to complete their semester project. Also, if the students are not motivated to learn and allocate the necessary effort, the group will not succeed. Development of the professional/methodological competencies is a must, and is usually well taken care of at the examination. However, as we have noted, the three other types of competencies are also important, but they are not typically an explicit part of the examination or deliberate competency development.

The final questionnaire expresses the students' perception of their increased competencies. Although we do not know what the non-respondents would have answered, it is interesting that about half of the students, on reflection, have found that all four types of competencies have been developed. In addition to the final questionnaire, the observations during the semester and interviews with students after the semester support and augment the results of the questionnaire:

- The introduction of inductive methods in the marketing course led some of the students to conclude that they were now responsible for their own learning.
- The student groups were able to resolve individual differences and to develop a common solution that implied organising their work effort.
- The statements made by the students in the questionnaire indicate some specific points of learning.

In its more than 10 years of existence, the GBE programme has regularly been assessed intuitively by noting the reaction and feedback of students and by observing the acceptance by industry. However, the observations, interviews and questionnaires provide substantial evidence that the PBL and the way it is realised in the third GBE semester stimulate development of a broad spectrum of competencies that students will appreciate in their professional career.

Thus, the findings show that experiential learning, inclusive of PBL, is capable of developing a broad spectrum of competencies. And the questionnaire appears to be able to serve as an instrument for providing a measure of increased competencies. Moreover, the detailed comments of students clearly indicate that filling in the questionnaire has been an opportunity for them to reflect on their learning, thus stimulating externalisation of tacit knowledge to explicit knowledge.

4.1.4. Discussion of RQ2: conditions for dealing with complex and ill-structured problems and for developing innovative and integrated solutions

The semester project of the third semester of the GBE programme certainly belongs to the very open-ended problems with many unknowns and aspects to be integrated. In particular, the TURBO introduction was a great challenge for the students asking them to develop a new business model on a fuzzy market. Furthermore, the students were encouraged to be innovative. Within the time frame of the TURBO introduction, the student groups were able to cope with this fuzzy and complex situation and at the end to present a coherent solution including a timetable for its implementation. The successful results may partly be attributed to the learning methods that were adapted to this type of problem, for example, close facilitation of the first day of the TURBO introduction, support during the following two days, and specification of the items to be addressed in the final presentation. Other elements of the semester also offered opportunities for the students to address open-ended problems. They were supported by various didactic methods, for example, guidance of the inductive learning in the marketing course, controlled learning during the finance game, regular status meeting for all students and supervisors' support during the semester project.

Both the TURBO introduction and the semester project called for integration of different disciplines and perspectives into a coherent solution. It was interesting to observe that during the TURBO introduction, the development of even rough budgetary financial statements served as a fruitful vehicle for integration of disciplines and perspectives. For example, a proposed product design posed a question of its impact on customer reaction, and an idea of how to ship products to customers spurred ideas on logistics.

The approach of Integrated Product Development and Agile Project Management includes the development of a series of prototypes as a means of speeding the learning process, because each prototype lends itself to a comprehensive evaluation. Interviews with students indicate that some groups in fact developed several prototypes; however, it was not done as a systematic learning process. This suggests that more emphasis be assigned to guiding the student groups in applying prototyping and following a phased process of engineering design, for example, ideation, maturity of ideas, concept development and detailed specification of solution.

The learning from the TURBO introduction was not perceived by the students as useful for coping with the subsequent semester project, although it was meant as an introduction to the semester project. One explanation may be that the students were not asked to reflect on their experience from the TURBO introduction; another may be that supervisors of the semester project did not encourage the students to make use of their experience from the TURBO introduction.

The experiment indicates that it is possible to develop capabilities for innovative and integrated solutions. At the same time, the following conditions may be identified:

- *Situated guidance and facilitation*. In the experiment, the facilitator was clearly aware of the need to guide the students in the initial phase, for example, he assisted the students in making initial assumptions and in scoping the problem during an iterative process. Gradually, the students were let loose to generate their own ideas and develop innovative ideas, supported by the facilitator. It was also helpful for the students to be informed of the specific points to be covered in their final presentation.
- No specific model exists for how to guide and facilitate a student team, and there may be different attitudes among teachers whether a teacher or facilitator should become actively involved in helping the team, or she/he should only intervene if the team gets astray.

- One of the key barriers to collaboration across disciplines that Richter and Paretti (2009) found was lack of integrative knowledge. This is essentially what we wanted to strengthen. As mentioned, the development of rough budgetary financial statements served as a vehicle for integrating different perspectives.
- *Intuitive understanding of the problem*. According to the interviews of students from the previous year, it was difficult to imagine what the real problem was for their semester project. That impeded idea generation and their intuitive evaluation of proposed solutions. This year's problem of both the TURBO introduction and the semester project, on the other hand, was more readily comprehended, and after initial discussion lent itself to fruitful idea generation. They were able to use their common understanding and to develop ideas on the basis of intuitive imagination.
- Puente, Van Eijck, and Jochems (2015) argue along the same line that a project problem should be realistic. If possible, students may be given an opportunity to interview potential users.
- *A safe way through for students*. With the open-ended problem calling for innovativeness, there is a risk that a student team after thorough analysis and detailed design reaches the conclusion that its business model is not viable. The team may have demonstrated capabilities for idea generation, scoping, analyses, as well as development of an integrated solution, and it is only fair that the students should be able to obtain a good grade. In the experiment, the facilitator did not address this issue explicitly. However, during coaching, he was able to convince the students that they should not worry.
- Facilitators should be aware of securing a safe way through for a student team, and the students should be told that evaluation criteria include learning process elements. We have observed that students are rather conservative in planning their project, probably because they want to increase their chances of getting a good grade.
- *Teachers should be trained for a new role*. The PBL approach implies a new role for teachers in the direction of facilitating the student group by guiding their learning process, rather than reviewing theories and offering well-defined solutions. This is even more critical when the problem of the project is very complex and open-ended.
- The facilitator had many years of industrial experience in holding workshops. Also, a group of teachers and advisors had worked with PBL for years. However, not all teachers were interested in engaging in fuzzy front-end issues.
- Puente, Van Eijck, and Jochems (2015) present a development programme in which they trained teachers and obtained significant improvements. Similarly, the Aalborg University offers training in facilitation of student teams as part of a programme for all new assistant professors. Crawford, Broer, and Bastiaansen (2006) suggest that facilitators have industrial experience.

4.1.5. Discussion on RQ3: reflection as an element of experiential learning

Reflection is an essential part of the Kolb model. As mentioned above, the final questionnaire clearly shows that students are able to reflect on what they had learnt by writing statements related to all four types of competencies. Also, the interviews with students revealed that they were able to identify important elements of their working mode, for example, the organisation of their team. On the other hand, we observed that the students apparently did not reflect on their experience from the TURBO introduction, and thus refrained from using it in the subsequent semester project. This has led us to conclude that students do not automatically engage in a reflection process; it needs to be organised.

The positive result of using reflection to stimulate learning in engineering education has encouraged us to further explore its potential.

Although there has been a growing interest in including reflection as part of engineering education, for example, Moon (1999), Boud, Keogh, and Walker (1985), Nueckles, Huebner, and Renkl (2009), McCrindle and Christensen (1995) and Choulier, Picard, and Weite (2007), to a large extent, it has been neglected. It has been left to the students to reflect on their gained knowledge and competencies. A reason for this is the apparent difficulties of measuring whether students' reflection indicates increased learning, as compared to traditional examinations on factual knowledge.

In the GBE programme so far, the semester project has primarily been seen as instrumental for applying theory and methods in a meaningful way to a practical problem. Faculty members and students have had a clear focus on the final solution, and not on the process of developing a solution including idea generation and development of a set of feasible solutions. Despite the fact that developing a solution to an open-ended and complex problem does not have only one best solution, the students had the impression that it was important to reach one solution and to be able to argue for it.

Admitting that it is essential that engineering students are able to develop an innovative and well-balanced solution (product), we need to realise that the semester project is a means of learning and not an end in itself. This calls for increased focus on the process of working as a professional engineer, for example, to include reflection on how the student group arrived at their solution (product). Instead of leaving it to the individual student to gradually acquire proficiency in dealing with complex and ill-structured problems, there is a great potential for increasing their learning by organising reflection in one way or the other.

To deal with the fuzzy front end of a complex and ill-structured problem is indeed a challenging learning process. When students are confronted with this situation for the first time, as was the case in the third semester, they have no compass to guide them apart from the facilitator's instruction. Their experience may seem like 'white noise' making reflection weak. The only thing that students may have learnt is that they are able to cope with such a fuzzy situation, which may encourage them to engage in similar open-ended problems another time.

After their first experience and attempt to externalise their tacit knowledge, they may be introduced to methods for idea generation, means of integration and prototyping, and so on. A subsequent semester project would then serve as an opportunity to experiment followed by reflection. This suggests that learning the proficiency of a professional engineer should be seen as a process spanning several semesters. In addition to the first three types of knowledge conversion, according to the Nonaka and Takeushi model, also internalisation may take place leading to engineering graduates that are conscientious of their professional competencies.

4.2. PDCA-Phase 4: act

In line with the PDCA approach, the GBE experiment was an eye-opener for the faculty members involved and served as a basis for developing a plan for the following semester. Consequently, the changes of didactical methods are now seen as part of a learning process for faculty members. An action plan for the next year's third semester includes an effort to more systematically stimulate and observe the learning during the semester:

- The TURBO introduction of developing a business model should be maintained, however, modified on the basis of ideas from students and faculty. A reflection session may be included after the TURBO introduction so as to make more explicit the students' learning and to support the use of learning outcomes during the subsequent semester project. The first one to two weeks should also include an introduction to the semester project both in terms of subject and scope of the project task and with respect to the groups' working mode.
- To further support students in dealing with uncertainty and open problems, the semester project should be carried out in three phases. In the first phase, while the main working load is on courses, the student groups should stay in an analysing mode trying to understand the situation and exploring opportunities without committing themselves to a specific solution. This may still provide a basis for applying relevant theories and methods. The next phase aims to develop one solution in the course of limited time. A series of prototypes may be useful to ensure a coherent and integrated solution. The result will be documented in a report. The third phase takes the solution from the previous phase as point of departure and aims to subject the solution to a

number of different conditions and assumptions, that is, a simulation of a spectrum of different situations. The phase may also address the integration issue, and the students' effort will be documented in a report.

- Following the aim to develop personal competencies by reflection ('learning to learn'), the two reports from the second phase and third phase should include a session on the students' reflection. In this way, students are asked to indicate what they have learnt, especially with respect to their working mode. Both reports should constitute the basis for the oral examination to realise an aligned course.

As a part of the ongoing improvement process, the first version of the planned changes was successfully implemented in the fall 2014. Especially, the students were urged to distinguish between the analysis/design phase and the reflection phase. This element turned out to support the students' general understanding of the complex interplay between the many parameters. The events in the fall 2014 support the PDCA method of a continuous organisational learning process.

5. Conclusion and implications

In view of the challenges confronting industrial enterprises, an experiment was carried out in the third semester of the GBE programme at Aalborg University aimed at introducing additional experiential learning methods. In particular, we were interested in identifying conditions for training the student in dealing with complex and ill-structured problems of forming a new business. As this includes a fuzzy front end with a creative and innovative process, learning cannot be measured in traditional, quantitative terms, we explored the use of reflection to convert tacit knowledge to explicit knowledge.

The experiment adopted a PDCA approach and included a three-day introductory workshop on developing a new business opportunity, a shift of learning style in a marketing course, and the introduction of a finance game. It concluded with developing a plan for new learning initiatives in the following year's semester.

The findings may be summarised as a number of implications:

- *PBL develops more competencies than ordinarily measured at the examination*. Especially, the social/communication and personal competencies are developed. This could be further strengthened if students are stimulated to reflect on these competencies. Also, the final examination may be adjusted to address other competencies than the traditional professional/methodological competencies to realise an aligned course. However, this will require recognition of the complex nature of measuring students' competencies that are not suitable for a standardised scheme.
- *Students are capable of dealing with a complex and ambiguous problem, if properly guided*. And they are able to develop innovative solutions that integrate different disciplines and perspectives. This suggests increased focus on coaching students, admitting to the fact that the nature and extent of guidance change over time. Four conditions for succeeding in letting students deal with a fuzzy front-end design problem were identified: (1) situated guidance and facilitation, (2) intuitive understanding of the problem, (3) a safe way through for students and (4) teachers should be trained for a new role. Adoption of Integrated Production Development and Agile Project Management methods of prototyping may also be helpful.
- *Most students are not conscious of their learning, but are able to reflect if properly encouraged*. This points to a significant potential for letting students become more explicit about their learning and competence development. Learning through reflection and experimentation should be given more attention. For example, the proposed three-phased semester project seeks to stimulate learning by asking students to simulate alternative ideas and solutions. This suggests assigning more weight to the learning process at the expense of primary focus on the end result.

- *Improving engineering education should be considered as an organisational learning process*, as demonstrated by the PDCA approach. Teachers and supervisors may have to change attitude and working modes; new ways of stimulating learning, for example, through reflection, should be experimented with to augment traditional 'product' oriented assessment.

The experiment has drawn attention to new directions for future research. For example, (1) to study the conditions for letting students successfully cope with complex and ill-structured problems, and to explore how a development plan may be initiated; (2) to study how to measure the spectrum of competencies developed during a course, a semester and a whole study programme and (3) to explore new examination forms that include outcome of students' learning processes, for example, by means of students' own reflection.

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No potential conflict of interest was reported by the authors.

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