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Conceptualizations on Innovation Competency in a Problem- and Project-Based Learning Curriculum: From an Activity Theory Perspective*

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Understanding innovation competency is the first step in fostering innovative engineers as conceptualizations can both enhance and inhibit innovative behaviors. Though literature is replete with discussions on conceptualizing innovation competency, there is much disagreement regarding its concepts as well as about how to put into operation the concept in teaching and learning. This paper addresses the disagreement through an empirical study in one problem- and project-based learning (PBL) curriculum. A case study on an engineering master program, Environment Management (EM), in Aalborg University, Denmark, has been conducted to answer the following questions. 1) How have academic staff conceptualized innovation competency in the PBL curriculum? 2) How have students conceptualized innovation competency in the PBL curriculum? 3) What are the similarities and differences between academic staff and students' conceptualizations? 4) How are academic staff and students' conceptualizations on innovation competency differentiated and related in concepts in the literature? This study encompasses eighteen in-depth interviews with academic staff and students. Conceptualizations on innovation competency were identified by analyzing the narratives of interviewees and coding the transcriptions into pre-prepared categories, based on the theoretical framework inspired by activity theory. The analysis of empirical data indicates a collaborative nature of innovation competency in the PBL curriculum; emphasizes the empowerment of individuals during teamwork; displays the interaction between individuals, teams and the social system. Furthermore, it describes innovation competency as a wide range of human abilities and processes, such as personal ability (in finding real-life problems and formulating research questions), interpersonal ability (by being open and responsive to diverse perspectives and intentionally constructing collaborative relationships), and implementing ability (by effectively implementing their ideas in useful projects).

Keywords: conceptualizations; innovation competency; problem- and project-based curriculum; activity theory

1. Introduction

Innovation competency has been identified as a key ability in engineering education to address economic growth and national competition. In Europe, innovation competency has been formulated as a goal for higher education, together with the abilities of collaboration, entrepreneurship and employability [1, 2]. In an educational environment, innovation competency can be conceptualized broadly as a community activity or narrowly as a highly restricted domain such as a student's cognitive thinking [3]. Conceptualizations have been examined in a wide context and in depth [4–7], because they may facilitate or inhibit students' innovative behavior [8, 9].

Conceptualizations can be regarded as one core element in the learning process in line with experimentation, experience and reflection [10]. Meanwhile, a number of studies found that what teachers and students know about innovation competency and what they do to foster innovation competency are limited and sometimes controversial [11–13]. Some research also indicates that ambiguities in conceptualizations on innovation competency might hinder the development of students' innovative ideas and behavior [14]. A conceptualization is an abstract, simplified view of the world that we wish to represent for a specific purpose [15]. Conceptualizations differ not only in their content and form, but also in the purpose for which they were developed. It is thus apparent that an important issue is how academic staff and students, the main active subjects of curriculum practice, conceptualize the nature of innovation competency in effective curriculum models.

With regard to the curriculum model, Europe has stressed the importance of student-centered learning in order to educate innovative engineers [16]. Engineering education institutions, scholars and educational practitioners develop strategies to re-design and re-organize curricula from teacher-centered learning to student-centered learning. Among these efforts, problem- and project-based learning (PBL) curricula have been viewed as one of the effective ways to facilitate students' innovation competency [17–19]. However, the learning activity for innovation often remains tacit in the PBL curricular and conceptualizations on innovation

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competency are explicit in the teaching and learning. Therefore, there is a fundamental need to find out how innovation competency is conceptualized and understood in the PBL curriculum, since these conceptualizations from the empirical field could be helpful in understanding it. During the teaching and learning process, both academic staff and students bring and develop their conceptualizations from their own experience and aims. A comparative study of academic and students' conceptualizations is also needed, as they both actively participate in the curriculum.

The PBL curriculum addresses both the content and the learners' development. Content is organized into the problem-based and project-based curriculum, as well as into the lectures that support the project [20]. The main concern of the PBL curriculum is the Learners' development. In addition to exploring the content, the PBL curriculum also aims to help students to develop flexible knowledge, effective problem-solving skills, self-directed learning, effective collaboration skills and intrinsic motivation [21]. This paper links the PBL curricular and innovation competency at a university in Denmark. The research questions for this study are:

1. How have academic staff conceptualized innovation competency in the PBL curriculum?
2. How have students conceptualized innovation competency in the PBL curriculum?
3. What are the similarities and differences between the academic staff's and students' conceptualizations?
4. How have academic staff's and students' conceptualizations of innovation competency differed from and been related to concepts in the literature?

2. Critical review of conceptualizations of innovation competency

A number of conceptualized definitions and theoretical approaches have led to practical attempts to understand innovation competency. However, they varied considerably with different perspectives and approaches. In this section, a brief review and critique of the current literature on conceptualizations of innovation competency has been provided in order to clarify the starting point of this study.

2.1 Chaos in defining innovation competency

There are multiple scales on which to understand innovation competency: the individual scale, which assumes the individual nature of innovation competency and its traits, such as personality [22, 23]; the team scale, which addresses innovation competency in a teamwork context [24]; and the system scale, which describes innovation competency in a system [25]. Within or among these scales, there is much disagreement. It is far beyond this paper to carry out a complete literature review or discussion of the disagreement on innovation competency. However, they are illustrated below to serve as the starting point for this paper.

Taking the premise that the process of innovation competency is based on individuals, studies describe an innovative person in the terms of: 1) personality; 2) cognitive characteristics; 3) abilities. The personality approach has placed an emphasis on personality variables, such as self-confidence, risk taking and independence [26]. The cognitive approach focused on mental traits, including open-mindedness, flexibility, novelty and so on [27]. The abilities approach has included a consideration of the innovation process and showed the practical abilities towards innovation [28]. The literature identified the major characteristics of an innovative person (Table 1).

Instead of positioning it on an individual level, innovation competency is also widely defined as an interactive process within teams [36–38]. These researchers regard innovation as a teamwork process by arguing that innovation is a continuous process that consists of the participation of people and the interaction among them [37]. However, there is disagreement within this scale on team size, team diversity, and conflicts.

Some scholars hold that large teams are more likely to be innovative [39–41]. Some believe that large teams may lack commitment, experience, have more conflicts and become ineffective in innovation [42–45], while small team are more aware of team goals and are better acquainted with other team members' personalities, work roles and communication styles [46]. A range of specific group size numbers are also found easily in the literatures [47, 48]. However, there is no empirical study to explore this issue in engineering education in the PBL context.

There are three groups of scholars, each claiming that there is a positive, negative or insignificant effect of diversity on team innovations. From the positive perspective, differences in expertise, knowledge and the perspectives of team members could contribute to innovative ideas and solutions [49–50]. From the negative perspective, diversity may disrupt the functioning of a group due to in-group/out-group categorizations [51, 52]. Meanwhile, some empirical researches found there to be insignificant effects on team innovation [53, 54].

Several empirical studies found that task conflicts positively influence team innovation [55], while some found that conflicts in relationships hindered the development of innovation competency in teams [56]. On the positive side, task conflicts evidently

Table 1. Summary of the major characteristics of an innovative person.

	Sources							
	A[28]	**B[29]**	**C[30]**	**D[31]**	**E[32]**	**F[33]**	**G[34]**	**H[35]**
Cognitive traits								
Open-minded			×		×		×	
Flexible			×					
Novelty			×		×		×	
Personality								
Risk taking			×					
Self-confident			×	×	×			
Curiosity			×	×	×			
Independent				×	×			
***A*bility**								
Problem-solving		×						
Cooperating	×	×				×		×
Autonomy	×							
Focusing and discipline	×					×		
Transfer and combination	×	×						
Communication		×					×	×
Practical abilities							×	
Creative abilities						×		
Engagement ability						×		×

foster deeper understanding of task issues and an exchange of information and these conflicts could facilitate team innovation by collaborative problem solving [57]. On the negative side, conflicts in relationships would impede effective collaboration and the exchange of knowledge and diverse perspectives in cross-functional teams [58]. Some results from empirical studies also provide evidence of the negative effect of relationship conflicts on innovation competency [59, 60].

More recently, many scholars have worked on innovation competency from a systematic viewpoint. For example, Pluker *et al*. define innovation competency as "the interactions among aptitude, process, and environment by which an individual or group produces a perceptible product that is both novel and useful as defined within a social context" [61]. Amabile describes it as the confluence of intrinsic motivation, domain-relevant knowledge and abilities, and creativity relevant skills [62]. Csikszentmihalyi highlights the interaction of the individual, domain and field. An individual draws upon information in a domain and transforms or extends it via cognitive processes, personality traits, and motivation. The field, consisting of people who control or influence a domain, evaluates and selects new ideas. The domain, a culturally defined symbol system, preserves and transmits creative products to other individuals and future generations [63]. Miettinen summarized recent tendencies and concluded a distributed view of network innovation, which described innovation as activating other actors and turning their interests into making their participation necessary. Meanwhile, he emphasized the importance of combining heterogeneous cultural resources and knowledge by horizontal networking across the boundaries of knowledge and activity domains [64]. Besides having different definitions, several paradoxes have also been identified, as displaying on Table 2.

2.2 Limitations in current conceptualizations

As stated above, researchers are in little agreement in defining and understanding what is meant by

Table 2. The paradoxes of innovation competency from the system view [65]

Dimension	**Poles of the paradox**	**Examples of characteristics**
Process	Convergent thinking	Reapplying the known, being fast and accurate, being strictly logical
	Divergent thinking	Branching out, making unexpected links, seeing surprising implications
Product	Routine	Effective, accurate, conventional
	Creative	Surprising, seminal, germinal
Press	High demand	Problems and nature of desired solution closely defined by management, high pressure for quick results, high demand for accuracy, low tolerance of error or failure, rewards for being right, high status given to people who fit in well
	Low demand	Problems and nature of solutions loosely defined, low pressure for quick results, tolerance of "good" errors, rewards for opening up perspectives, high status given to people who are "different"

"innovation competency". Their definitions had the following limitations.

First, the literature review reveals that, although certain common characteristics have been identified, there is no consensus or operational concept of what innovation competency means in the context of education. On the team scale, researchers mainly examined the factors that may have an impact on innovation competency and failed to explore the nature and the process of innovation competency. The systematic view of innovation competency described both the environment and process. However, it failed to put teamwork, which is the essence of problem- and project-based learning, under scrutiny.

Secondly, most researchers are overly preoccupied with one particular scale—an individual, team, or systematic scale as stated above—rather than looking at the network connections that run through and across these scales. For instance, the individual perspective on innovation competency addresses the traits and characteristics of students. It promotes self-direction, however, it fails to recognize the dynamic relationship among different elements in educational systems. In contrast, the systematic perspective places emphasis on environment elements and previous experience but it fails to clearly identify and recognize the important role of individual students and teamwork. Thus there is a notable value in investigating conceptualizations of innovation competency without making assumptions in certain learning contexts.

Thirdly, most theories of innovation competency tend to emphasize the role of cognitive thinking, or experience and practice, and they usually fail to acknowledge the essential role of conceptual/technical (e.g. engineering) knowledge and a closely related curriculum mode (e.g. PBL curriculum) in the educational context. Conceptualizations exist in some area of interest and the relationships that occur among them [66].

With regard to engineering education, technical/conceptual knowledge provides both academic staff and students with systematic and fundamental basics for facilitating and learning towards innovation competency. Thus conceptualizations in engineering education might differ from others as the purpose of educating professional engineers. Meanwhile, it is necessary to understand innovation competency in the light of pedagogy and the learning philosophies that underpin PBL.

3. Theoretical framework

Facing these critiques, a comprehensive framework based on activity theory is applied to address the complexity of innovation competency and PBL context. Activity theory offers a framework for describing multifaceted activity and provides a set of perspectives on practices that interlink individual and social levels [67, 68]. This was initially articulated by the efforts of Lev Vygotsky [69] and was subsequently developed both in the Soviet Union [67] and in the West [68]. An activity system is the basic unit of analysis of activity theory. It consists of certain components. Each component is dynamic and continuously interacts with others through which is defined the activity system as a whole. It can be understood to be a group of people or a community where common objects are shared and tools are used to act on objects. It also refers to subjects with competence, preferences and goals that act in relation to objects. Meanwhile, agents act as participants in a larger social system, referred to as a community. As participants who are engaged in this social system where certain rules (principles of administration and management) apply, the action and interaction between participants is regulated by a degree of division of labor, which can be understood as having both a horizontal division and a vertical division among subjects [70]. Scholars researching education have applied it in order to focus on interactions between humans and system components with the goal of building human capacity and the environment [68].

With regard to the teaching and learning process, elements of the whole activity have been appropriated by teachers and students, for example, how tools such as materials and a physical facility are used; how rules are development and applied during the learning process; what kinds of problems and learning outcomes are viewed as valuable and innovative. In this sense, innovative behaviors are regulated by conceptualizations both on the PBL curriculum and in innovation competency. Thus innovation competency is not simply the student–tool interactions that are fundamental to understand, but also the participants–object interactions as mediated by tools that are provided in the PBL curriculum. In this study, activity theory expands the unit of analysis from the cognitive thinking of individual students to the entire activity system. Meanwhile, it divides and investigates the subject (e.g. students) and the social context in a holistic framework. What is more, the knowledge from this study can be further applied to the improvement of PBL curriculum practice. In this study, the overall activity set consists of the PBL curriculum in Aalborg University as a whole, which works together to achieve community goals. From the perspective of activity theory, there are seven elements in the PBL curriculum as interpreted in Table 3.

Table 3. Elements in the activity system for this study

Elements	PBL curriculum	Conceptualizing innovation competency
Subject	Academic staff or /and Students	Positioning scale Individual, team or system
Object	Academic staff's educational objectives; Students' expectation and motivation	Describing innovation competency Cognitive traits, personality or abilities
Tools	Tool used to make the objectives become true	Documenting supportive tools
Rules	Rules to regulate academic staff and students	Understanding rules: implicit or explicit
Community	Actors involved in this whole activity	Describing the system
Division of labor	Different roles and responsibilities of students and academic staff	Team scale. team members System scale. academic staff, team members and others
Outcome	Students' development team projects	Individual performance or/and; Team product.

4. Methodology

4.1 Selection of the case: EM program in Aalborg University

Because the case study approach can provide detailed descriptions of the complex phenomena under investigation [71], this study adopts a case study approach for data collection. The Master of Science Program in Environmental Management (EM) at Aalborg University (Denmark) has been selected as the case to be studied because it is a typical Master's program with a well-practiced PBL curriculum. EM mixes both Danish and international students and is taught in English. Aalborg University was established in 1974; it has been characterized by designing the problem- and project-based learning curriculum. It differentiates itself from older and more traditional Danish universities due to its pedagogical structure, which is based on problem-centered, real-life projects of educational and research relevance. This model is internationally known and recognized as "The Aalborg Experiment" or "The Aalborg Model" [72]. The Environment Management program aims to cultivate professional environmental engineers and leaders who can solve sustainability-related problems in private or public organizations.

The curriculum for this program is organized into four semesters over two years. Each academic year, there are approximately 35 students (50% Danish and 50% foreign). The work on a project report and in courses (related to the theme) covers approximately 80% of each semester and is equivalent to 24 ECTS (European Credit Transfer System). The rest of the semester is made up of fundamental courses or other compulsory courses. Project work is formulated within the framework of the given themes and is related to the overall educational objectives, which can be broad, open themes or subject-related limited themes. Students are allowed to formulate their project proposal themselves. Students are expected to attend the courses and apply the knowledge gained from them in their project work. The output of the courses is assessed along with the project work at the end of the semester.

4.2 Data collection

This study applied a three-stage collection process (see Table 4) in order to obtain rigorous interview data. Data generation on the EM program mainly came from replies to in-depth interviews in the second stage. The target interviewees were the academic staff and students participating in the curriculum. Interviewees included academic staff (men and women at the assistant, associate, and full professor level) and students from the EM program. Half of the academic staff that supervised student project work were selected. Also one of the program establishers and one of the program coordinators were interviewed. In total, eight academic staff members (50% of the total) from the EM program and ten students (two different groups in two semesters, 33% of the total) were interviewed from 1 September 2009 to 25 June 2010. According to the concepts of Lincoln and Guba [73], the sample size should be large enough to provide informational redundancy. With regard to this study, half of the academic staff that taught lectures and supervised students was selected to participate in this study. With regard to the students, we chose an international group that included both Danish students and foreign students in each semester; this amounted to two groups over two semesters. Both groups consisted of five people, which is the typical group size in this program. Thus, the breadth of interviewees ensures that the study is sufficiently in depth and focused on the topic.

4.3 Data analyzing

This study employed semi-structured interviews consisting of open-ended questions. The interviews were designed to collect descriptive data in the

Table 4. Data collection process in the EM program at Aalborg University

<table>
<tr><th colspan="6">Data Collection Process</th></tr>
<tr><td>Stage 1</td><td colspan="2">Academic staff</td><td colspan="2">Students</td><td>Others</td></tr>
<tr><td rowspan="2">Tentative Interviews</td><td colspan="2">Interivewed with an academic staff from Medical Department.</td><td colspan="2">Interviewed with 2 master students from other programs.</td><td>Interviewed a Ph.D student who graduated from EM program.</td></tr>
<tr><td colspan="5">Intention and usage:
1) try to suspend all spontaneous judgment while interviewing;
2) to improve interivew guidelines and process.</td></tr>
<tr><td>Stage 2</td><td colspan="5">Collecting data for this study</td></tr>
<tr><td rowspan="4">Interviews in the field</td><td>Academic staff (8 in total)</td><td colspan="4">Students (10 in total)</td></tr>
<tr><td>Supervisor L</td><td>Group 1</td><td>Group size 5</td><td>Individual interivew</td><td>A, B, C, D, E</td></tr>
<tr><td>Supervisor M</td><td>Group 2</td><td>Group size 5</td><td>Individual interivew</td><td>F, G, H, I, J</td></tr>
<tr><td>Supervisors N, O, P, Q
Program establisher R
Program coordinator S</td><td colspan="4">Usage:
1) First hand data for conducting this research;
2) Data for analysing to answer research qestions.</td></tr>
<tr><td>Stage 3</td><td colspan="5">Verifying the data with insiders</td></tr>
<tr><td>Checking Data</td><td colspan="2">Presenting the draft to the students, supervisors and scholars .</td><td colspan="2">Listening their comments
Integrating their comments</td><td>Usage: Rflection and verification</td></tr>
</table>

interviewees' own words and develop insights into the interviewees' conceptualization. The majority of questions fell under the interview guidelines (see Table 5) determined prior to the interview. Word order was modified on site and additional relevant questions were posed, depending on the interviewer's perception of the flow of the interview. For example, some of the data reported in this paper came from responses to interview prompts such as "What do you mean by innovation competency in group work?". Meanwhile, the interviewees' own words will be used to explain their conceptualizations instead of using the technical academic concepts from the literature.

Each interview can also be followed by an evaluation, which considers questions such as: 1)What new information (concepts, reasoning, etc.) did the interview provide? 2) Does any of this new information open new conceptualizations in the answering of the overall research question? 3) How can this new information be tested/broadened in later interviews? and 4) How does the new information fit into information from previous interviews?

Each interview lasted between 1 and 1.5 hours. The interviews were transcribed following a transcription style sheet to maintain the same conventions throughout. The transcriptions were thematically analyzed in two cycles: first, identifying the text that used explicit concepts, and second, coding the identified text and classifying and organizing the ideas into a framework that can describe how interviewees used the concepts.

The academic staff and students' conceptualizations on innovation competency from the transcripts were analyzed through the seven themes: objects, subjects, tools, rules, division of labor, community, and outcome (as showed on Table 5). These themes are based on the logic of activity

Table 5. Coding themes and the checklist for interviewing guidelines

Coding themes	Checklist for interviewing guidelines
Subject	Who make innovation happen in PBL curriculum? One single student, a group of students or academic staff? Who do you think as innovative in your group? What kind of ideas or behaviors do you think are innovative? What kind of groups do you think is capable of generating innovation?
Object	What is the object of this project? What is the purpose of group project for this program? Personal skills or innovative project? Or what else? What are the students working on? What are the academic staff working on? How is innovation valued in your teaching/learning? What do you think innovation means to you during your teaching/learning?
Tools	What do you think of the tools used in the project? What tool is helpful for cultivating innovation competency?
Rules	What kind of rules are used in the project? In what ways do you think they can affect innovation competency?
Community	Which community is involved in this activity? Which group of people worked together to achieve the object? How were they involved in the process of innovation?
Division of labor	Who does what in this project? Who determines what is meaningful?
Outcome	What is produced in this project as innovation competency?

theory that is used in order to interpret the emerging issues in a consistent way. The "objects" were the goals planned to be achieved in an activity. The "subjects" were those making the objects become true from both the academic staff and students' points of view. "Tools" indicated the factors considered to be effective for developing innovation competency and "rules" referred to the common way the learning and innovation process was managed. The "division of labor" described the power distribution, which was related to the subjects' relationships. Coding under the "community" gave the social context in the PBL curriculum, which refers to all the actors in the activity system. The "outcome" displayed the product of the whole activity.

5. Research findings

In this section, the results of empirical work are presented through themes: objects, subjects, tools, division of labor, and community, according to the theoretical framework provided by activity theory. These findings address the research questions from the comparative analysis of academic staff and students' conceptualization.

5.1 Subjects developing innovation competency in PBL curricula

Academic staff

Interestingly, all of the academic staff emphatically agreed that students were the masters of their own learning and that they owned the whole project. To be specific, they thought that each group was the master of the teamwork. During the teamwork, each student was asked to be active as an independent learner and collaborative team worker. Thus, from the perspective of the academic staff, the students were responsible for their own development of innovation competency through their group work. They took themselves as facilitators in students' learning process. An associate professor said:

> Students themselves should always be responsible for their learning in the PBL curriculum. We are here to help them as facilitators by helping them to reflect on their work and build connections with government and companies. We are here to support students' learning by providing real-life settings.

These academic staff positioned themselves as facilitators, rather than as participants, in a clear and consistent way. Meanwhile, they stressed the importance of self-directed learning in developing the innovation competency.

Students

Students indicated one whole team as the subject of projects in the PBL curricular. Regarding skill-development, they thought that individual students should take on the responsibility of self-learning. However, they thought that the academic staff played an important role in the learning process and they expected academic staff to be more involved. For example, a student said:

> As doing the project in a group, I and other group members share the responsibility and work. For example, I need to be self-disciplined and show my respect and support for other group members. Other group members should contribute too. If you are talking about my own professional development, such as gaining knowledge or developing skills during projects, I think it mainly depends on myself. We have to be responsible to both self-learning and project work. However, I feel our supervisor should give us more clear directions and specific support.

As discussed above, both academic staff and students agreed that group members were the owners of the projects, on which innovation relies. However, academic staff took the group as the subject of the project work and the individual student as the subject of his/her learning. Students considered the whole group to be one collective subject for the group project, while they considered individuals to be the subjects of self-learning and skill-development.

5.2 Innovation competency as an object of PBL curriculum

Academic staff

All of the academic staff addressed the importance of cultivating innovation competency since it is important for a professional engineer. The project process was most often linked with innovation competency. The following quote from an assistant professor illustrates this linkage:

> For me, creativity (or innovation competency) is about generating new ideas and making things useful in the real world. . . . To formulate the problem and solve it through the project work . . . the problem should be a problem that exists in the real world . . . it's sort of a must for the profession as an engineer nowadays.

Skills and abilities supporting new ideas in the project process were considered as part of innovation competency. For example, they referred to problem-formulation skills (figuring out research questions from complex phenomena, methodological skills (the ability to choose and apply proper theories and methods), analysis skills (the ability to solve problems), and communication skills (the ability to sell new idea and discuss effectively with others), implementation skills (the ability to conduct their research with group members, companies and others). The following statement shows how the project process impacts innovation competency:

> Constructing a new theoretical framework for the project, using the theories to solve real-life problems, generating new concepts or new understandings of specific conceptions and so on . . . any capacity can contribute to new knowledge . . . .

With regard to working problems, academic staff frequently mentioned the "real world" to describe where the problems should come from and the relevant types of problems. They stressed that every student can be innovative:

> I don't think it's just for geniuses . . . every student can be innovative . . . I mean each student has the potentials to be innovative. It's not a matter of talents. It's a matter of solving problems in a creative way.

Students

For the students, innovation competency was also a familiar term because their project work asked them to start with a real-life problem and solve it in a new way. However, some of them perceived it as a talent and indicated that their learning objectives were not in fact developing innovation competency, but developing professional skills through academic achievement. One student said:

> I don't exactly know what you mean by innovation competency. However, it must be some kind of talent. I don't think we have to develop such abilities. It's not so important. In order to be a professional engineer, the most important thing is doing well on our project.

In contrast, other students differentiated innovation competency from talent by pointing out that innovation competency is potentially a common quality among ordinary people. They also thought the innovation competency to be an individual ability to create something new and useful. Since some students emphasized that the product of innovation competency must be something new and useful, students thought that only new solutions for real-life problem within their project work could be called innovation.

Concerning the process of innovation competency, students found it difficult to describe it clearly. They referred to it as thinking innovatively to create new ideas and selling those ideas to put them into use.

In conclusion, it seems that academic staff pay more attention to the process of innovation competency, while students conceptualized innovation competency according to innovative products. Likewise, academic staff perceived the innovation competency to stem from group work, while students interpreted it as individual academic performance.

5.3 Tools for developing innovation competency

Academic staff

The academic staff viewed nearly all elements of the PBL curriculum as tools to motivate students to think innovatively and broaden their points of view. They thought that lectures could help students gain basic knowledge that would help them to explore the real world. The teamwork was seen as the best way to make the students gain a deep understanding of the knowledge and put it into practice. The group room (physical facilities) became a place for students to practice communication, an important skill for innovation today. The assessment motivated students to reflect on what they had done. As mentioned above, the academic staff viewed themselves as tools for the innovation competency and the students as the ones who made innovation happen in the project. Meanwhile, the academic staff addressed the importance of self-directed learning in encouraging students to think creatively and critically. As facilitators in the PBL curriculum, they also agreed that the principles of problem- and project-based learning, such as putting students at the center of the curriculum and working on real-life problems in groups were positive pedagogy strategies for innovation competency.

Students

Students thought that the physical facilities at Aalborg University, like the coffee corners situated about the building, provided convenient spaces for spontaneous discussion. Besides the public spaces, group rooms are available for each project group during the semester at Aalborg University. Students in the EM program have unlimited access to their group room throughout the semester. The "ownership" of a group room helps the students to have a more active role in their project. The room was used as a workplace and coffee bar to communicate with group members and supervisors. With regard to the physical environment, students said that they feel safe and comfortable studying at Aalborg University. Meanwhile, students highly agreed that the PBL curriculum positively impacted on the development of innovation competency. However, besides self-directed learning, students expected academic staff to do more.

5.4 Rules facilitating innovation competency

Academic staff

According to a statement by an academic staff member, group participation and collaboration were the rules for managing innovation in a PBL curriculum. A teacher said:

> Tell them it's up to them what they want to do for their

> project at the start of each semester. And let them know working together is a must and participation is their responsibility. If they don't know how to work together, they should construct a project management system by themselves.

As for being the supervisor, some academic staff also mentioned the importance of not being hard on "mistakes" and defining problems. From their perspective, the tolerance of mistakes and ill-structured problems are good for the students to bring up new ideas and perspectives.

Students

Students also highlighted the PBL principles of rules, which are good for innovation competency. However, students stressed the importance of rules in group work, such as attending group meetings, respecting differences, being disciplined when listening and discussing, and managing time and the project. Individually, they all agreed that each group member should be responsible to the team and respect other team members, understand what must be done to be effective in a team setting, follow through on commitments, and maintain an appropriate balance between listening and speaking. One student said:

> Every team member should be contributing to the project. And we should all be aware of our differences. It's important to come to meetings on time, finish each part of your job, and communicate in a polite and effective way.

Besides the team-rule, students appreciated the freedom in the PBL curriculum. For example, students from the EM program are free to develop a voluntary, student-led group and to work on problems set by themselves, companies, government or their supervisors. That is to say that students from the EM program can mix together for group work. As 50% of the students are international students, many groups will consist of students from different cultural and education backgrounds. Students are also free to work with students from other Master's programs if the project is related to the semester theme. Students found this freedom was important for them to conduct innovative projects, to make mistakes and to explore widely.

As stated above, both academic staff and students used PBL project rules to discipline themselves and manage group work in order to make innovation happen. Academic staff were more concerned with the students' awareness of these rules, but the students were more preoccupied with forming more detailed learning regulations for the whole group.

5.5 Conceptualization on division of labor

Instead of teacher-directed curriculum as in a traditional curriculum, the PBL curriculum puts students at the center of all the teaching and learning. Academic staff believed that a student-directed learning context could provide spaces for students to generate new ideas. To support student-directed learning, distributed leadership was important to both academic staff and students. One assistant professor said:

> All the teaching and learning should take students' need and interests as the start point. And the project should be managed by all of the students. They should equally work together.

Regarding the project process, academic staff and students all agreed that students played several roles in implementing innovative ideas. For example, there were creators who created innovative ideas and found real-life problems, refiners who always tried to find potential problems within the project, implementers who implemented the whole project, and advancers who were good at convincing others to accept their ideas. Each student could play some of these roles or only one of them. To address this, academic staff put emphasis on the distributed leadership among group members at the start of the group-formulation. And they facilitated each student to act independently during the project.

5.6 Conceptualizations on community

Academic staff

The academic staff were proud of their community, which offered many opportunities for students to participate in real-world problem solving. Students at Aalborg University work on real-life problems that can be related to several disciplines. A connected and interdisciplinary environment has been fostered through program cooperation. The EM program combines areas such as environmental planning, environmental policy, environmental management systems (EMS), corporate social responsibility, logical framework analysis, life cycle assessment (LCA), and energy analysis and planning. The academic staff believed this type of community was important to develop innovation competency. One of them said:

> Students can work with other students who are from Sustainable Energy Plan Management, a Master's program that goes together with EM on the course schedule and project agenda, and uses different interdisciplinary tools for project design, environmental monitoring, quality control and evaluations, as well as planning. Furthermore, students can gain interdisciplinary supervision since most staff members themselves are doing interdisciplinary research and have a rich interdisciplinary experience. This interdisciplinary environment is helpful for developing innovation competency.

Students are required to develop solutions to problems in real time in the Aalborg PBL curriculum. Most real-life problems come from real practice in industry and governments. As the academic staff said, the university–industry–government partnership, which has been very well developed at Aalborg University, gives student projects a high potential for innovation. The staff believed the process of working on real-life based problems could develop the skills and competencies for innovative ideas and the solution to real-world problems. One assistant professor said:

> Since they (the students) are working on real-life problems, most of their projects need to get support from the industry or government. It is very helpful for them to develop innovative ideas and useful solutions.

Academic staff presented the learning community in the PBL curriculum in a very positive way. They even considered interdisciplinary study and real-life experience as the essence of the PBL curriculum. Meanwhile, these two characteristics of the PBL curriculum were described as being the supportive context for facilitating innovation from the academic staff's perspective.

With regard to specific group composition, the academic staff said that they always encourage students to form groups of between 3 and 6 people from different cultural and educational backgrounds. They mentioned that conflicts occurred during the teamwork. They simply took it as a common phenomenon, which might be good for students in developing communication and collaboration skills.

Students

Regarding their specific projects, students indicated that the diverse community is very supportive in their learning and teamwork. Starting from the group-formulation, students were encouraged to get into a group with students from different countries and educational backgrounds. They commented that this diverse composition is one way to open up new perspectives but they felt frustrated when conflicts occurred. Most often, they took the conflicts to be a waste of time and to be negative for their project. However, they highly agreed with academic staff on the best size for a team (3–6).

Based on the interview data, the academic staff and students agreed that the PBL curriculum is a diverse context that includes academic staff (who facilitate students' learning), the students (who learn and develop themselves through different backgrounds), companies and the public sector (which can provide the research data for students' project, i.e. the city hall in Aalborg). However, the students had a negative opinion of conflicts, while academic staff regarded them as positive.

5.7 Conceptualization on the innovative outcomes

Academic staff

To address the outcome, the academic staff expected innovation competency both during the process and in the final product. They mentioned innovation as follows: newness in the learning process is brought out—a new plan that solves a problem, a new theory that reorganizes existing knowledge, or a strategy that guides actions; usefulness in the final project—a feasible solution to a real-life problem. Specifically, the academic staff described students' development of innovation competency as an innovative problem-solving process, which takes its point of departure from solving real-life problems, works on taking new ideas into implementation, and ends with a new solution, product or knowledge within group collaboration and interaction.

Students

Discussing the outcome of the whole learning process, students mainly mentioned the final project and their own academic performance evaluated by academic staff. They argued that:

> As long as we can see, it only can be considered as an innovative project as we've got a good score from it. Until then, we know we did a great job.

But they often agreed that they gained skills and abilities on finding real-life problems, communication and collaboration, which could not be evaluated at the final examination.

6. Discussions

With regard to the first research question, "How do academic staff conceptualize innovation competency in a PBL curriculum?", our study reveals that academic staff who participated in our study conceptualized innovation competency as a key factor for engineering education. They highly stressed the ability to solve "real-world" engineering problems innovatively. Moreover, most of the interviewees thought innovation competency could be developed in every student. With regard to teaching and supervision in the PBL curriculum, academic staff appeared confident in their teaching and the effectiveness of the PBL curricula on educating innovators. Furthermore, they regarded innovation competency as part of the agenda of Aalborg's PBL curricula.

With regard to the second research question, "How do students conceptualize their innovation competency and its development in a PBL curriculum?", the majority of students believed that everyone could be innovative. Yet students seemed less satisfied with the support they had and did not feel well informed and supported in their project work. Since students are given opportunities to express innovative ideas and make mistakes, they find the PBL curriculum to be a comfortable and democratic learning environment. In addition, the students were in remarkable agreement regarding the need for more supervision and management, especially the international students who had never been through a student-centered curriculum before.

With regard to the third question, "What are the similarities and differences between the academic staff and students' conceptualizations on innovation competency?", a few contrasting conceptualizations were found between academic staff and students (as shown on Table 6). Taking the conceptualized "outcome" as an example, academic staff expected innovation competency both during the process and in the final product. However, students take only the product of their project as the outcome of innovation competency. Apart from the similarities and differences stated above, the academic staff's conceptualizations were deep, open, predominantly associated with the pedagogy of the problem- and project-based learning curriculum and aligned with the principle of "teaching for innovation". However, the students' conceptualizations were much more narrow and concerned with the learning expectations of "being professional". Students thought it was difficult to develop self-directed learning towards innovation in the project. This difficulty suggests that innovation competency needs to be addressed and supported more directly by the academic staff.

With regard to the fourth question, "How academic staff and students' conceptualizations on innovation competency differentiated from and related to concepts in the literature", academic staff and students' conceptualizations are positioning innovation competency as an individual ability based on team collaboration on three scales (individual, team and system). However, they emphasized the import role of teamwork and social environment as the tools and situated the community transforming educational objective in personal competency. Instead of the different views in the literatures, both the academic staff and students suggested 3 to 6 people as being the best size for a team; agreed on the supportive rules and community in the PBL curriculum; and demonstrated the importance of distributed leadership and self-directed learning. A specific comparative description is given in Table 6.

7. Conclusions

In the light of these results, both academic staff and students agreed on the importance for engineers to be innovative. They all take innovation competency as an individual competency, which is generated by individuals, interactions, and the learning environ-

Table 6. A comparative description of conceptualization among academic staff, students and the literature

Themes		**Academic staff**	**Students**	**Literature**
Subject	Individual	×	×	×
	Team	×	×	×
	System			×
Object	Cognitive traits			×
	Personality			×
	Abilities (Individual)	×	×	×
Tools	Self-directed learning	×	×	
	Team work	×	×	
	PBL Supervision	×	×	
	Physical facility	×	×	
Rules	Collaboration	×	×	
	Participation	×	×	
	Tolerance of errors	×		
	Loosely defined problems and solution	×		×
	Rewards for opening up perspectives	×		×
	High status given to people who are "different"			×
Community	Team size	(3–6)	(3–6)	Inclusive
	Team diversity	Positive for innovation	Positive for innovation	Inclusive
	Conflicts	Positive	Negative	Task positive; Relationship negative
	Interdisciplinary	Positive	Positive	
Division of labor	Student directed	×	×	
	Distributed leadership	×	×	
Outcome	Product	×	×	×
	Process	×		×

ment in social–cultural contexts. As stated, it involves a wide range of human abilities and processes, such as personal ability (in finding real-life problems and formulating research questions), interpersonal ability (by being open and responsive to diverse perspectives and constructing collaborative relationships intentionally), and implementing ability (by effectively implementing their ideas to useful projects).

As illustrated by the comprehensive conceptualizations above, innovation competency has a much more specific meaning to academic staff and students engaged in the PBL curriculum than has typically been measured by empirical research on this topic. It indicates that resulting standards and well-designed indicators may probably diminish the validity of educational research. Thus, conceptualizations on innovation competency should be investigated in more detail by researchers through in-depth interviews and observations with a large sample size of cases from different programs and universities, as our case number limits our findings.

Regarding the chaos in conceptualizing innovation competency in the literature, the results of this study indicate the collaborative nature of personal innovation competency in the PBL curriculum; emphasize the empowerment of individuals and groups based on educational and social context; display an interactive activity among individuals, teams and system; and show one well-organized project learning approach to educate innovative engineers using real-life problems. Consequently, other researchers' findings that the PBL curriculum was an effective model may not necessary lead us to assume that it serves an extremely important function in developing innovation competency. However, the data from an activity theory perspective indicate self-directed learning, PBL teamwork and supervision to be the tools to develop innovation competency. This understanding of innovation competency in the PBL curriculum could be a reference for other engineering educational practice, and a better mutual understanding among academic staff and students could be reached. Meanwhile, the application of activity theory provides a framework to investigate innovation competency in curriculum practice.

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