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Developing Students' Collaborative Skills in Interdisciplinary Learning Environments*

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In the light of increasing demands on engineering curricula to integrate the development of professional skills in engineering education, this paper focuses on characteristics of effective educational environments and experiences for preparing students for future challenges by exploring ways in which professional learning is encouraged. The study is empirically grounded in a 3-day annual workshop that brings together students from all areas in the building sector including industry exponents to engage collaboratively in the processes of design and construction of a new building. The workshop is based on the principles of Building Information Modeling (BIM), which facilitate the coordination and collaboration between parties of a building design and construction team, and in this process, essential communication and interpersonal skills are mobilized and developed. Data about the students' learning outcome are collected through observation, interviews and online questionnaires. The present investigation points at the dual effect of experiential learning in problem-based, interdisciplinary environments with regard to both actualizing core knowledge, skills and competences through solving complex real life problems and having to employ and thereby develop professional skills in the process of solving these problems.

Keywords: collaboration skills; interdisciplinary teams; digitally supported collaboration environment; problem based learning

1. Introduction

The role of engineers has grown increasingly complex during the last couple of decades. Not only do engineers need to demonstrate up-to-date knowledge and capabilities within engineering practice and technological proficiency including ICT, but they also have to respond to a diversity of stakeholder demands and perform competitively at a global level and deliver increased value corresponsive to the elevated costs and remuneration systems in OECD countries. Future engineers are expected to reach beyond their technical expertise into transdisciplinary domains and align competing perspectives that match societal and global complexity as they "*synthetize information from a broad range of disciplines and understand the constraints of social systems as well as the economic, legal and political constraints of an engineering design solution*" [1]. Consequently, there is a growing interest in the engineering community worldwide to qualify graduates for work in a changing global economy and with problems demanding competencies that transcend traditional disciplinary norms. In addition to traditional 'hard' skills and ICT, knowledge economies require a diversified set of 'soft' skills such as adaptability and problem solving, communication skills, teamwork and interdisciplinary competence as well as self-facilitation in terms of motivation for work and leadership. In order to meet the 21st century demands, universities are thus requested to prepare students to act autonomously within and beyond their disciplines [1].

Aware of the raising demands on engineering, the various accreditation organizations worldwide are engaged in assisting institutions define adequate graduate attribute mappings or program outcomes by providing criteria that also include professional or transferable skills to form the profiles of future engineering graduates. At the European level, attempts have been made to unify the national standards through the founding in 2006 of The European Network for the Accreditation of Engineering Education. In 2008, ENAEE approved the EUR-ACE framework [2] standards for the European accreditation of engineering programs consisting of five core skills areas, i.e. knowledge and understanding, engineering analysis, engineering design, investigations and engineering practice; supplemented by a set of generic or transferable skills including teamwork, effective communication and leadership across different disciplines and levels, as well as professional ethics and awareness of societal and global issues. Similarly, the recognized US Accreditation Board for Engineering and Technology, ABET, had already in 1996 issued a new set of criteria in which the traditional 'hard' engineering skills were complemented by an addi-

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tional set of six 'soft' or professional skills including the ability to communicate effectively and to work in multidisciplinary teams, ethics and professionalism, as well as working within a global and societal context, lifelong learning and a knowledge of contemporary issues [3]. Furthermore, the Engineer of 2020 report [1] provides a strategic framework for the attributes and skills for future engineers, which combines strong analytical skills, creativity and practical ingenuity with communication skills, professionalism and leadership. In 2006, the National Science Foundation funded the P-360 study, which provides empirical guidance for engineering programs primarily within design and problem solving skills, interdisciplinary competence and contextual competence [4].

2. Beyond hard-soft divide

Universities are organized along fixed disciplinary lines and corresponding epistemological structures. To prove successful in their fields, students are supposed to assimilate disciplinary norms, the 'ways of thinking and practicing' (WTP), of their discipline [5]. Traditionally, engineering belongs to the so called hard disciplines being overtly paradigmatic regarding the nature of knowing and understanding including what counts as adequate methods for problem solving [6]. The 'hard', technical emphasis within engineers' identities might not comply with 'soft' competencies that not being part of this identity might be marginalized as alien to WTP in engineering. Meanwhile, the global call for complementing modern engineering curricula with generic skills related to communication, teamwork, professionalism, problem solving and contextual awareness challenges traditional disciplinary confines and habitual WTP towards a more integral vision of engineering arguably involving interdisciplinary collaboration. Interdisciplinarity has been defined as the *"process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline or profession . . . and [that] draws upon disciplinary perspectives and integrates their insights through the construction of a more comprehensive perspective"* [7, p.5]. Building interdisciplinary competence requires a space for discursive and methodological negotiation to facilitate the creation of alliances between communities of practice and their WTP without threatening participants' disciplinary identities. It is argued that transcending the 'hard' versus 'soft' disciplinary divide and facilitating cross-disciplinary encounters to expand discipline-specific activity are necessary steps in aligning university activity with 21st century societal and global requirements [1]. Interdisciplinary collaboration might prove helpful in transcending the hard/soft disciplinary identities as it promotes the development of generic competences related to 'graduateness' qualities, i.e. the "*academic inquiry and intellectual curiosity, the ability to accommodate diversity and alternative perspectives, the ability to create and defend ideas, and the ability to use communication as a vehicle for learning*" [8, p.456]. Arguably, these qualities are conducive to the advancement of professional skills in engineering education.

The principle of learning through solving problems seems crucial for developing deep learning as it involves a focus on practice in context and activates various process competencies, e.g. communication, team collaboration, etc. Problem Based Learning (PBL) marks an innovative turn in this respect as it mobilizes higher order thinking and inquiry-based processes based on students' autonomy in pursuing learning objectives [9]. Interdisciplinarity is closely associated with PBL as it makes indispensable the construction of knowledge through dialogical processes denotative of PBL, whereby students negotiate meaning and a shared problem solving, which further develops their understanding [10]. Interdisciplinary collaboration promotes student learning in both an educational and a professional sense by providing problem oriented work with competing perspectives on knowledge derived from a diversified disciplinary perspective.

In the light of increasing demands on engineering curricula to integrate the development of professional skills, the present paper focuses on characteristics of effective educational environments and learning experiences for preparing students for future challenges by exploring and identifying ways in which professional learning is encouraged. To elucidate this point, the paper will investigate an extracurricular activity, a 3-day interdisciplinary workshop that engaged engineering students together with other relevant stakeholders in a collaborative digital building project. The focus areas of the workshop are new tools and collaboration methods to meet increasing requirements on the building sector as described in the section below. The study will explore the main impacts of interdisciplinary collaboration related to the development of professional skills, and discuss possible implications for improvements in engineering education. The research question guiding our investigation is: Which are some of the characteristics of effective learning environments and learning experiences that will better prepare engineering students for the world of work and how can the educational setting promote the development of professional skills?

3. Collaboration needs in the construction industry

Emerging trends in civil engineering pose increasing requirements on the building sector in the form of significantly increased tailored user demands, complex heating, ventilation and air conditioning installations, sustainability, innovative architecture, increased focus on operation and maintenance as well as an increased expectation for social responsibility and accountability. Engineering competences have to be continually adjusted to match the speed of technological change, the exponential increase in the amount of data and information that is becoming available, the globalization of the industry and of the engineering practice. In many countries we see very ambitious requirements to new buildings regarding energy consumption and environmental 'footprint'. With the new requirements, we first of all need to use state of the art components like highly insulated walls and windows as well as very efficient systems for energy conversion and energy distribution. Additionally, it is necessary to combine the technologies in an optimal way for the individual building and also to see the individual building as a part of a larger energy consumption, production, distribution and storage system. Such requirements can only be fulfilled with a very close interdisciplinary collaboration between several engineering disciplines as well as other disciplines involved in design, construction and operation of buildings. To interact successfully in such complex collaboration settings, we must take into account technological, organizational, personal and interpersonal aspects.

The interdisciplinary collaboration will typically take place in a multi-model environment reflecting differences in the representation of information about the building to be designed and built. In a study of industry requirements for collaboration in Building Information Modeling, Shafiq et al. [11] found that there is a considerable difference between the requirements for collaboration within a single discipline and the collaboration across multiple disciplines. Dolenc et al. [12] discusses the communication challenges on both technical and semantic level in developing a collaboration platform for the construction industry. Klinc et al. [13] have studied requirements for engineering collaboration and states that the architecture, engineering and construction businesses are very information intensive and that "the most important component of every project remains the collaboration and sharing of the information amongst different parties". During the last decades, a large research effort has been made to create the foundation for an integrated building design environment to support the collaborative process between end users, designers and contractors. Christiansson et al. [14] describe how an integrated design environment should support a design process partly carried through in virtual spaces with access to a shared building product model on different detailing levels. Several initiatives involving information technology are taking place to increase collaboration in the building industry and keep up with the evolving requirements. Similarly, educational and formational settings respond to industry needs for preparing candidates that are fit for purpose by finding ways to expose students to real work life requirements.

During the last decade, the concept *Building Information Modeling (BIM)* has evolved as an overall term for the new modeling paradigms and collaboration processes in the building industry. It facilitates the coordination and collaboration between the parties of a building design and construction team. BIM has the potential to transform the cross-disciplinary approach used in the industry today, since it supports a close collaboration in more iterative processes where each discipline's contribution can be continually merged into the project. BIM both requires and supports interdisciplinary collaboration and is therefore suggested as a means to promote interdisciplinary in engineering programs [15]. BIM reverberates the principles of interdisciplinarity in that the integrated design approach distributes equal responsibilities among participants, making collaboration vital to solving problems. At the same time this supports an interdisciplinary way of thinking since it brings participants together to meetings and discussions, supports the sharing of knowledge, expertise and experiences to make sure that building performance is thought through and that each system or design decision is not optimized at the expense of another.

This study is empirically anchored in a 3-day annual workshop in Northern Denmark, The Digital Days (DD), which is based on the principles of BIM. The workshop brings together students from all areas involved in the building sector including industry exponents to experience technological and organizational possibilities and challenges as well as skills requirements. The participants in DD have a shared goal that is to solve a real life problem in an authentic context. In this case, the participants had the common task to work through most aspects of design and construction of a hospital building according to specific requirements. Another real life authentic dimension was provided by inviting a team of architecture students from the University of Architecture in Ho Chi Minh City, Vietnam, to present their take on the problem. The Danish interdisciplinary work group were thus confronted with the reality of global competitiveness of solutions from a highly motivated, product oriented team and the option of taking into account their proposition, which added yet another dimension to the collaboration process.

4. Data collection and results

The collected data stem from inquiries during the entire workshop, where two of the research team members acted as process facilitators, including observation and informal talks with the working groups with special focus on the engineering students. A main part of the data collection was based on an online questionnaire on participants' evaluation of the workshop and the perceived learning effect including professional skills. A similar evaluation was conducted with industry representatives as per the relevance of the workshop to work life. The questionnaires were supplemented by a number of interviews with selected students and industry representatives. Further data stem from a final evaluation meeting with all participant groups, who shared their learning experiences and feedback on the workshop. The data have been treated as a collected body of evidence using an interpretivist methodology [16]. The survey that was conducted at the end of DD testifies of students' subjective perception of their learning, on a 5 point scale (1 = low; 5 = high), pertaining to 14 different statements for both before and after the workshop. 51 out of 83 students answered, 19 were engineering students.

4.1 Perceived effects on student's professional learning

Following the overall participant rating, engineering students' learning level was in 12 out of the following 14 parameters perceived higher after the workshop than before:

1. I am aware of the elements which are part of the building process.
2. I am aware of my function in the building process.
3. I have an insight in the competences of the other professional groups.
4. I can shift between being in charge and letting go of control.
5. I am capable of negotiating with other people to reach a decision.
6. I am capable of cooperating with other people in order to solve a problem.
7. I learn a lot from other people when we work in a group.
8. I am capable of communicating my ideas to other people.
9. I am capable of viewing things from other people's perspective.
10. I am aware of my own strengths and weaknesses.
11. I don't hesitate when confronted with a new unusual problem.
12. I have an increased interest in learning more within my professional area.
13. I am capable of grasping the various professional areas and see the connections between them.
14. I have a considerable knowledge within my professional area.

Figure 1 shows the evolvement during the Digital Days for the group of engineering students' perceived learning level within the 14 parameters. We focus on the highest/lowest ranked statements ranging between the maximum of 51 points and the minimum of 30 points, before and after DD. The statements that scored most points *before* DD were: st.7—*''I learn a lot from other people when we work in a group''* (51p.); st.12—*''I have an increased interest in learning more within my professional area''* (48p.); and st.11—*''I don't hesitate when confronted with a new unusual problem''* (44p.). While the first statement goes slightly up, 1.p, *after* the DD, the remaining two are the only ones which go down, 2p. and 1p. respectively. This shows that our students are initially confident in working in groups and working with problems since their curriculum is problem-based (PBL, AAU model). They are also dedicated to perfecting their core engineering competences. Apparently, these competencies were not in need of further development during DD, which explains the limited perceived change after DD. Remarkably, the statements with lowest scores before DD were the ones that evolved most during DD, namely: st.3—*''I have an insight in the competences of other professional groups''* (30–41, by 11p.); st.13—*''I am capable of grasping the various professional areas and see the connections between them''* (32–40, by 8p.); st.1—*''I am aware of the elements which are part of the building process''* (34–43, by 9p.), and st.4—*''I can shift between being in charge and letting go of control''* (34–39, by 5p.). Obviously, these skills areas although initially low, proved highly needed and were therefore mobilized during DD and subsequently developed. These are not core engineering skills, but rather professional ones involving collaboration, process as well as self-awareness. Further aspects pertaining to professional competence evolved during DD: st.9, by 4p.—*''I am capable of viewing things from other people's perspective''*; as well as: st.5—*I am capable of negotiating with other people to reach a decision''*; st.8—*''I am capable of communicating my ideas to other people''*; and st.10—*''I am aware of my own strengths and weaknesses''*, by 3p. These statements refer to students'

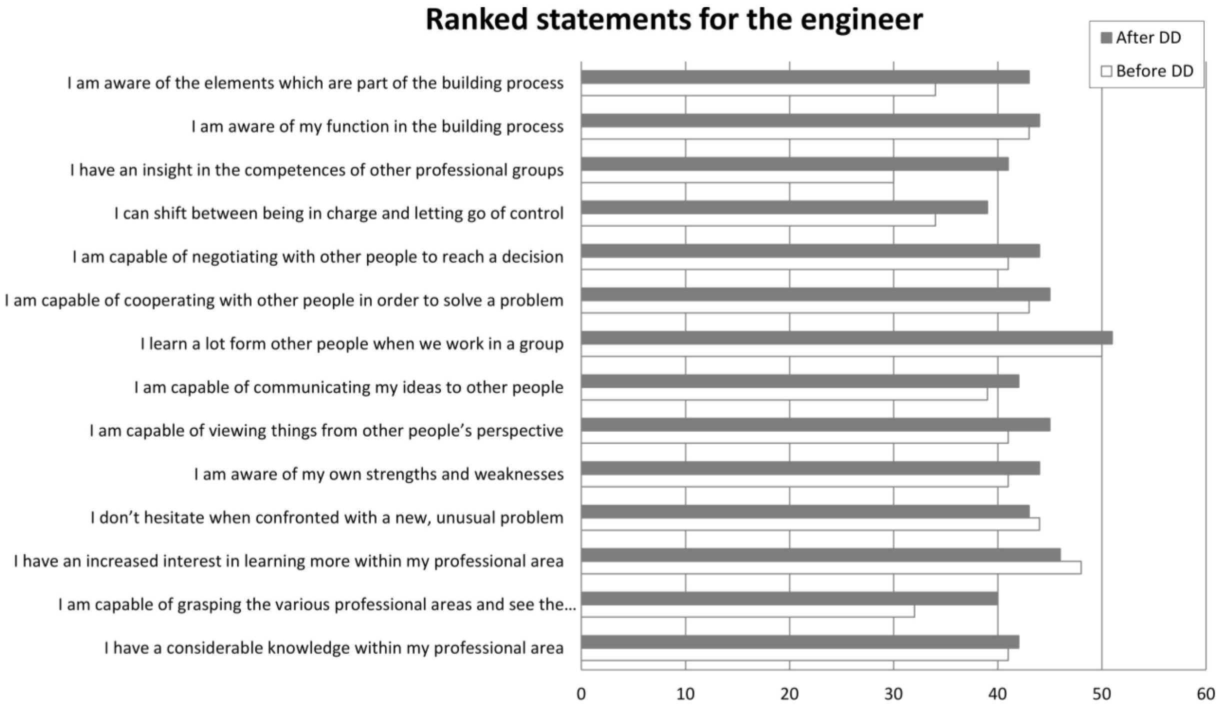

Fig. 1. The 14 parameters of perceived learning level of engineering students, before and after the DD. The bars show the total score from all 19 engineering students' answers.

ability to grasp diverse perspectives, communicate and negotiate solutions on a self-reflected basis. The rather moderate increase in points may not as such suffice to describe the actual development especially as it sums up the points on the entire scale.

Figure 2 shows a qualitatively more differentiated view of the points ascribed, where we can see a raise in the high-end of the scale, in relation to two pairs of statements, st.3 and st.13 among most evolved during DD, and st.5 and st.8, more specifically relating to communication and negotiation skills, arguably related to the activation of the interdisciplinary collaboration.

This overview gives an indication of the learning produced during DD as also being qualitatively higher as it contains points from the upper end of the scale, i.e. 4 Point (grey) and 5 Point (black). Especially the latter appears only in the aftermath of DD. Although based on subjective assessments of how the students think their competence levels may

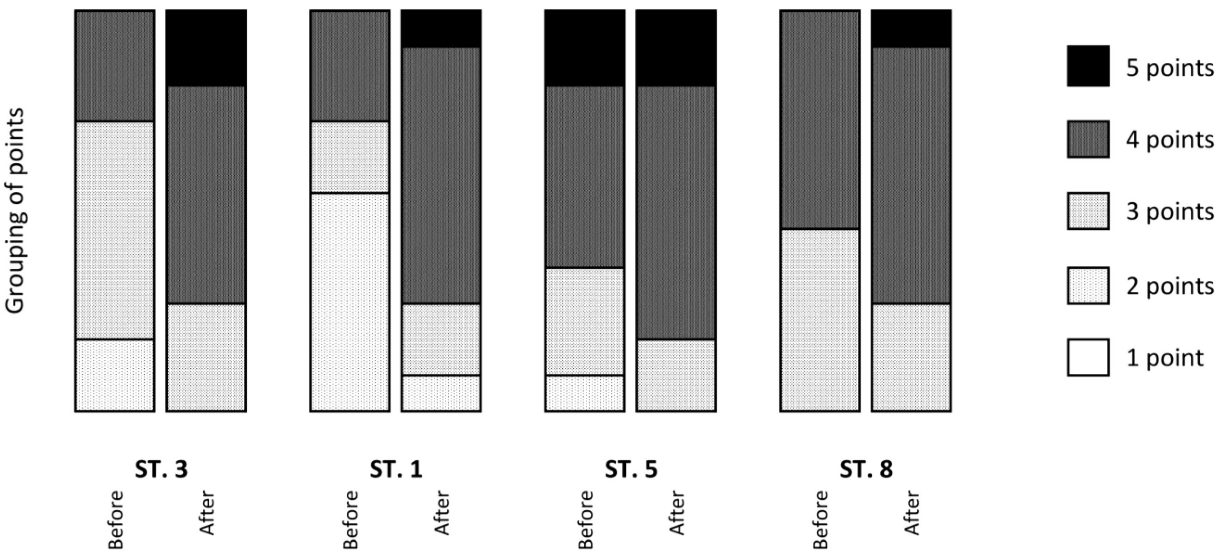

Fig. 2. An overview of the qualitative shift in the perceived learning effect during DD.

have shifted during DD, their appreciation is indicative of which competences were at stake during DD, where the students were involved in doing engineering in context, as part of complex scenarios in real life projects, in a quite different setup with a much more compressed schedule than the usual study groups and assignments. This forced the students to be flexible: work faster and make decisions based only on estimation, which they were not used to. Similarly, the new ways of working and the pressure felt from other professions, which depend on their output, may have challenged the usual disciplinary norms.

4.2 Developing professional skills through interdisciplinary collaboration

The scope of DD is to "*unite forces across disciplines and traditions... through purposeful cooperation with industry partners to develop and expand the use of digital tools throughout the building sector*" (B. Larsen, opening speech at DD). Besides the espoused practical goal, this statement has clear interdisciplinary connotations in aiming at the synergetic interaction beyond formal and informal disciplinary boundaries. The integration of the various disciplinary contributions during DD revolves around certain themes denotative of interdisciplinary collaboration. Communication plays a central role in mediating multiple perspectives and approaches to guide the problem-solving process. This aspect appears nearly unanimously in students' evaluations: *"DD is the only opportunity we as students have to communicate with other professional groups – all the technical stuff we learn in school, here we focus on something else"... "What we learned was communication"... "The effect of interdisciplinarity, the communication between [parties], really makes an impression"*.

Communication mediates the negotiation of meaning to reach a common understanding:

"I am more capable of talking about things with others before taking a final decision".

"I will definitely be better at communicating with people from other fields".

This leads to an increased insight in other disciplines and boosts interdisciplinary collaboration skills:

"I will be better at viewing problems from the other team members' perspective".

"I am more aware of—, and I can better relate to what the other professional groups do".

"[The biggest gain comes from] working in teams and communication with people from different specialties; then analyzing the problem with different approaches".

Meanwhile, the gains are linked to the final educational aim, i.e. being fit for practice:

"[The biggest gain comes from] the great collaboration between all the different groups. Because of this workshop, I will be capable of working in real life with a bit more experience than I would have if going out straight from school. I know what a real life job will be like and what working with a lot of people will be like. The workshop really prepares you and answers a lot of the questions you ask yourself before graduating".

In their evaluations, industry representatives strongly agree that the competencies, which the students achieve during the workshop, are highly relevant for working life, and also that the workshop reflects real life problems. Additional interview evidence stresses the importance of people skills: *". . . verbal communication, catching each other's signals, and how to handle a situation when things escalate. Here we are halfway into the psychological domain, could this be integrated in the [engineering] educational programs? They should have some insight; it doesn't come automatically. . ."* (IT-manager). However, the need to train specific digital tools, as those in focus in the workshop, are deemed to be equally valuable in the workplace: *"If they know how to use them, then we have a basis for cooperation; if they all learned it from school, it would help them speak the same language from the start"* (IT-manager). The interviewee stressed that the interdisciplinary work form at the workshop corresponds to an evolving work organization in Denmark, called "project houses", where all the specialists are gathered synchronously during the initial stages of a large project to plan and coordinate their contributions. This echoes the claim of many students at the final evaluation meeting, that the real gains were made in the interdisciplinary group meetings, where group representatives from all professional groups negotiated shared understanding and intentions: *"We just wish that all of us could have taken part in the interdisciplinary group meetings to gain a deeper insight in what other groups were doing"*.

The opportunity of training their collaborative skills in an interdisciplinary environment is highly valued by the participants: *"a huge advantage that all these professional groups are present because it gives a unique insight in what we all are doing and how to collaborate with other professional group than yours and strengthens our collaborative skills with different disciplines because we learn to understand their needs and requirements"*.

The digital platform BIM offers an adequate framework for developing interdisciplinary collaboration: *"... how suitable it is to store all data inside a drawing, which improves the collaboration between groups; and the different parts of the building process"*. BIM supports the need for trying out alternative solutions, where making mistakes is viewed as learning: *"[We valued] the chance to try out some ideas without causing everything to fall to the ground"... "... all that went wrong could be used to improve the system".*

Regarding problem solving and collaboration skills mobilized during DD, students emphasize the stimulating effect of real life problems: *"All the different problems, the more, the better, because they create opportunities for having to collaborate with others"* and: *"We discover problems with methods and tools that we wouldn't get to know in school".* Learning to handle uncertainty alters the perception of what counts as important, offering an alternative to a certain methodological rigidity in favour of processual skills, which challenge the dominant disciplinary norms: *"I concentrate on the type of knowledge that I can operate within an approximate appreciation, which seems 'constructable', without having to perform the entire calculation, so that I can bid in to keep the process going when other professional groups need my input".*

The dynamic social context boosted by the interdisciplinary collaboration in an authentic setting is particularly valued as a modeling factor and a strong motivation for engaging in complex problem solving in unknown circumstances: *"The large number of people working together on the same project is a strong motivation for self-improvement; gives a sort of real world experience"...* And: *The commitment of every group was a strong individual motivation for people".*

4.3 Developing professional skills in context

The main findings in the study concern the impact that a real life scenario evoking the mutual interdependencies and the complexity of a building project had on developing core professional skills, i.e. teamwork, communication and negotiation as well as the centrality of interdisciplinary collaboration in promoting these skills. Participants benefited not only from working in a team, but also from the process of negotiating solutions with other teams in a multidisciplinary, globally enhanced setting as the workshop was boosted by the concurrent participation of different occupational fields as well as a team of architecture students from Vietnam. Participants mobilized communicative skills and interpersonal competencies to uncover each other's discipline specific methods in order to align their problem solving approaches. Moreover, the socially facilitated experiential learning milieu prompted students' commitment and motivation to deal effectively with problems within the constraints of a project framework.

The value of a real life interdisciplinary problem scenario lied first and foremost in providing students with opportunities to activate generic skills in context, in this case, the integrated process of a building project. Consequently, the present investigation points at the dual effect of experiential learning with regard to both actualizing core knowledge, skills and competences through solving complex, real life problems and having to employ and thereby develop professional skills in the process of solving these problems in a multi-level, multi-disciplinary setting. Interdisciplinary collaboration became the meditation link between diverse perspectives on work and was instrumental in bringing about mutual awareness and insight. In this process, a whole set of processual skills were mobilized and developed, e.g. teamwork, effective communication across various disciplines and levels, flexibility and a sensitivity to different stakeholder perspectives as well as an increased self-awareness and leadership. Incidentally, these competencies correspond to the professional skills agreed upon by accreditation organs worldwide.

5. Discussions

Various problem and project-based learning models are increasingly adopted in engineering education, yet, our findings suggest that there may be further scope for applying methods to promote professional competencies. Interdisciplinary settings involving multiple university disciplines as well as various actors from the industry create socially facilitated, high-involvement learning environments. As one of the students during DD put it, *"[t]his type of workshop has the potential to expand disciplinary and interdisciplinary boundaries".* We will here discuss how interdisciplinary collaboration impacts on the development of professional skills and make some suggestions for deliberate action at curriculum level.

One of the salient features of interdisciplinary collaboration is the integrative problem solving aspect in combining contributions from multiple disciplines. The participants in DD moved beyond merely distributing tasks in a team towards negotiating solutions internally and with concurrent teams. They mobilized interpersonal and communicative skills in order to uncover and integrate each other's "ways of thinking and practicing". The prerequisite of such activities in DD was a real, complex work project containing imminent problems and adequate opportunities for the participants to negotiate shared solutions. The groups fed their contributions continually into a digital platform that supported iterative problem clarification and solution loops and thereby the interdisciplinary collaboration. Furthermore, the real-life scenario was populated by valued professionals and specialists, who served as role models for an attitudinal shift towards an integrative mindset. The experiential learning climate boosted participants' spirit of inquiry and freedom to advance preliminary solutions to open-ended problems. The dynamic social milieu promoted mutual commitment and a motivation to comply with the constraints of a product oriented approach, where interdisciplinary collaboration was instrumental to project work.

In our study, Problem Based Learning emerges as an adequate methodology for promoting the development of professional skills to the extent to which it is contextualized as real-life problem and project scenarios involving interdisciplinary collaboration with an explicit focus on the development of processual competencies through carefully designed mutual interdependencies in order to solve the problems and carry through with the project. These conditions challenge the students to collaborate in innovative ways developing flexible thinking and a sensitivity to the interdependency between various disciplinary contributions. This suggests that professional skills need not necessarily involve any radical expansion of the curriculum to include formal courses in related disciplines, such as communication, leadership, etc. Rather it would require experiential learning environments that demonstrate the need of non-technical competencies and facilitate their development by according them sufficient status and finding ways to assess students' demonstration of such skills.

Problem based learning aims explicitly at developing process skills [17], yet the way it is practiced within educational program confines, where students work in self-elected, homogenous groups on mutually agreed problems, leaves but a limited scope to engage collaboratively and activate communication skills in order to integrate expertise from related fields. To this purpose, stressing the interdisciplinary dimension in problem and project based learning might be a viable way to supplement the learning objectives of the formal curriculum. This learning goal should be pursued by allowing students to engage actively in carefully planned interdisciplinary activities and would have to be assessed formatively in order to encourage students' reflections and mutual sharing of their experiences with employing professional skills. Problem and project based learning, work on interdisciplinary real life projects; teamwork, interaction with industry; project management and formative assessment emerge as essential methods to develop interpersonal and professional competencies. This requires an attitudinal shift in the disciplinary ways of thinking and practicing traditionally stressing hard skills, and therefore engineering educators will have to advocate these new sets of skills in convincing ways, through sustained efforts to employ these methods, and their personal commitment to support students' professional learning.

The consequence of stressing the importance of interdisciplinary collaboration in engineering programs might be that the type of workshops reported in this study will not have to be marginalized as an extracurricular activity, subject to discretionary efforts, but rather become an integrated part of the formal curriculum, together with a number of related activities. Arguably, such a curriculum will release the grip of traditional disciplinary thinking allowing for the implementation of fully-fledged, interdisciplinary problem and project based learning environments, perhaps emulating the project-house work organization, evolving in industry. This would at the instructional level imply a new, interdisciplinary type of educator, equipped with specific competences to promote interdisciplinary thinking. In order to promote the development of professional skills through interdisciplinary collaboration among engineering students, the interdisciplinary competence has to be explicitly acknowledged as a learning goal in the educational program. Besides the formal, curriculum level, a framework for integrating the development of interdisciplinary competence in engineering education should involve organizational and instructional levels, i.e. explicit ways of organizing interdisciplinary learning environments, as well as the competence development level, i.e. equipping staff with the required insight and tools to facilitate students' professional learning processes.

6. Conclusions

This study is empirically anchored in a 3-day annual workshop which brings together engineering students with students from several other areas involved in the building sector. Based on data from a real-life building project, the students collaborate on all aspects of Architecture, Engineering and Construction. The collaboration is based on the concept Building Information Modeling (BIM), which has evolved as an overall term for new modeling paradigms and collaboration processes in the building industry.

The main findings in the study concern the impact that a real life scenario evoking the mutual interdependencies and the complexity of a building project has on developing core professional skills, i.e. teamwork, communication and negotiation as well as the centrality of interdisciplinary collaboration in promoting these skills. Participants benefited not only from working in a team, but also from the process of negotiating solutions with other teams in a complex multidisciplinary setting.

Various problem and project-based learning models are increasingly adopted in engineering education, yet, our findings suggest that there may be further scope for applying methods to promote professional competencies. Interdisciplinary settings involving multiple university disciplines as well as various actors from the industry create socially facilitated, high-involvement learning environments. According to the findings in this paper, such learning environments prompt students to mobilize interpersonal and communicative skills in order to uncover and integrate each other's "ways of thinking and practicing".

Mutual interdependencies challenge the students to collaborate in innovative ways and thus develop flexible thinking and sensitivity to the interdependency between various disciplinary contributions. This suggests that professional skills can be obtained without a radical expansion of the curriculum with formal courses in disciplines as communication, leadership etc. Rather it would require learning environments that exhibit the need of non-technical competencies and facilitate their development.

References

1. National Academy of Engineering, *The Engineer of 2020: Visions of Engineering in the New Century*, National Academies Press, Washington, DC, 2004.
2. European Network for Accreditation of Engineering Education, www.enaee.eu, accessed March 14th 2013.
3. ABET, Criteria for Accrediting Engineering Programs, Baltimore, Md.: Engineering Accreditation Commission, Nov. 11, 2003. See http://www.abet.org/criteria_eac.html, accessed March 14th 2013.
4. L. R. Lattuca, P. T. Terenzini and J. V. Volkwein, Prototyping the Engineer of 2020: A 360-degree Study of Effective Education, see *Final Report: Engineering change, A study of the impact of EC2000*, Baltimore Md., 2006.
5. D. Hounsell and C. Anderson, Ways of Thinking and Practicing in Biology and History: Disciplinary aspects of teaching and learning environments, in Kreber, C. (ed.), *The university and its disciplines: teaching and learning within and beyond disciplinary boundaries*, Routledge, London, 2009.
6. R. G. S. Matthew and J. Pritchard, Hard and soft—a useful way of thinking about disciplines? Reflections from engineering education on disciplinary identities, in Kreber, C. (ed.), *The university and its disciplines: teaching and learning within and beyond disciplinary boundaries*, Routledge, London, 2009.
7. L. R. Lattuca and D. Knight, In the Eye of the Beholder: Defining and Studying Interdisciplinarity, in Engineering Education, *Proceedings of the 117th Annual Conference & Exposition of the Association for the Study of Engineering Education*, Louisville, KY., 2010.
8. S. A. Barrie, Conceptual framework for the teaching and learning of generic graduate attributes, *Studies in Higher Education*, **32**(4), 2007, pp. 439–458.
9. M. Savin-Baden, Changing models and perspectives of problem- based learning, in E. De Graaf and A. Kolmos (editors): *Management of Change*, Taipeh, Rotterdam, 2007.
10. S. B. Merriam, R. S. Caffarella and L. M. Baumgartner, Learning in adulthood: A comprehensive guide (3rd ed.) *Jossey-Bass*, San Francisco, 2007.
11. M. T. Shafiq, J. Matthews and S. R. Lockley, A study of BIM collaboration requirements and available features in existing model collaboration systems. *Journal of Information Technology in Construction, ITcon,* **18**, p. 148–161. www.itcon.org/2013/8.
12. M. Dolenc, P. Katranuschkov, A. Gehre, K. Kurowski and Ž. Turk, The Integrated Platform for Virtual Organisations Interoperability, *Journal of Information Technology in Construction, ITcon*, **12**, p. 459–477, 2007, http://www.itcon.org/2007/30.
13. R. Klink, Ž. Turk and M. Dolenc, Engineering Collaboration 2.0: Requirements and Expectations, Journal *of Information Technology in Construction, ITcon* 14, Special Issue *Next Generation Construction IT: Technology Foresight, Future Studies, Roadmapping, and Scenario Planning*, pp. 473–488, 2009, http://www.itcon.org/2009/31.
14. P. Christiansson, K. Svidt and K. B. Sørensen, Future Integrated Design Environments, *Journal of Information Technology in Construction ITcon* **14**, Special Issue *Next Generation Construction IT: Technology Foresight, Future Studies, Roadmapping, and Scenario Planning*, pp. 445–460, 2009, http://www.itcon.org/2009/29.
15. M. J. Casey, Work in Progress: How Building Informational Modeling May Unify IT in the Civil Engineering Curriculum, *38th ASEE/IEEE Frontiers in Education Conference,* Saratoga Springs, NY, 2008.
16. F. Erickson, Qualitative research methods for science education, in B. J. Fraser and K. G. Tobin (eds.), *International Handbook of Science Education* (pp. 1155–73), Kluwer Academic Publishing, Dordrecht, 1998.
17. X. Y. Du and A. Kolmos, Process Competencies in a Problem and Project Based Learning Environment, in *Procs. SEFI 2006 Conference*, Uppsala, 2006.

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