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Building interdisciplinary collaboration skills through a digital building project

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1 INTRODUCTION: WHAT IS INTERDISCIPLINARITY?

Future engineers are expected to encompass a wide range of competencies, from technical specialists to transdisciplinary integrators aligning competing perspectives in response to societal complexity. They must "*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*" (The Engineer of 2020 reports).

Despite a consistent interest in interdisciplinarity in education in the last decades, there are still conceptual inconsistencies and confusion surrounding the term. There are divergent meanings of what it takes to claim interdisciplinarity versus multidisciplinarity, cross-disciplinarity, and transdisciplinarity. Common to all is that there are several disciplines involved. It is the manner of involvement which is different and ought to be kept distinct, if they are to inform decisions in educational planning and design. Lattuca (2010) distinguishes between the terms according to the degree of interrelatedness between disciplines. Multidisciplinarity represents the mere co-existence of two or more disciplines, each discipline maintaining its specific character with no attempt to integrate the various

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contributions into a cohesive whole. It is regarded as a central element in the engineering education as engineers are expected to work in multidisciplinary teams, where specific methods and tools from various areas of expertise are used to deal with a problem. Interdisciplinarity, on the other hand, is characterized by the integration of theories and methods, which are borrowed from one discipline and used in another. Cross-disciplinarity is regarded as a particular expression of such interaction in an attempt to connect and combine ideas and methods across disciplines, yet distinct from 'pure' interdisciplinarity, as it tends to confine itself to the mere reinterpretation of specific disciplinary concepts and issues in the light of another discipline.

The integrative aspect at the heart of interdisciplinarity denotes the synergetic interaction between specific disciplinary perspectives. Interdisciplinarity can thus be defined as *"a 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"* (Klein & Newell, quoted in Lattuca, 2010, p.5). Meanwhile, the extent of integration is determined by the scope of interdisciplinarity in a specific context. It can be described along a continuum delimited at the one end by informal communication and exchanges and, at the other, the homogeneous integration of disciplinary components. It is thus the specific problem and its context which initiate the integration process; this consists in identifying and aligning disciplinary contributions that define interdisciplinarity in that context. The ideal coordination among disciplines is denotative of transdisciplinarity, which describes temporary configurations of researchers from a variety of disciplines as well as social key stakeholders, brought together to solve problems in their contexts of application. Transdisciplinarity may in its capacity of mobilizing knowledge and competencies to solve specific problems in specific situations aptly describe much of the problem-centered work of practicing engineers, who engage with various actors to solve problems in ever changing situations and requirements.

Interdisciplinarity stands at the crossroads between education and practice, and in order to operate in this field, engineering graduates require interdisciplinary competence, i.e. *"an appreciation of various perspectives and an ability to incorporate and evaluate multiple disciplinary approaches in problem-solving"* (Lattuca 2010). The present paper points at cross-disciplinary collaboration skills as instrumental to interdisciplinary competence. To elucidate this point, we will examine an extra-curricular arrangement, to indicate key elements of cross-disciplinary collaboration that foster interdisciplinary competence. Finally, we will discuss the impact of certain curricular and instructional practices that may promote engineering students' building of interdisciplinary competence.

2 DISCIPLINARY CONSTRAINTS AND THE COMPETENCY DILEMMA

Different forms of knowledge give rise to the different disciplines, which are taught according to their epistemological structures, i.e. a set of concepts and rules for what constitutes inherent logical orders in each form of knowledge (Matthew and Pritchard, 2009). Universities are organized along fixed disciplinary lines; to prove successful in their fields, students are supposed to assimilate disciplinary norms, the "ways of thinking and practicing", of their discipline (Hounsell and Anderson, 2009). Traditionally, engineering knowledge belongs to the so called 'hard' disciplines, i.e. being overtly paradigmatic regarding the nature of knowing and understanding, at the risk of limiting the types of problems for study and what counts as appropriate methods for problem-solving (Matthew and Pritchard, 2009). This sets certain constraints to the development of flexible thinking and the continual renewal of underlying paradigms required to adapt to changes in a world of growing complexity. Similarly, current university structures as well as the 'soft' and 'hard' divide inhibit the integration of multiple disciplinary perspectives into a more comprehensive approach to problem solving.

Meanwhile, the industry is increasingly in demand of graduates with strong interdisciplinary skills, who can work successfully in interdisciplinary teams (Beddoes and Borrego, 2011). Considering the persistence of traditional disciplinary boundaries and the 'hard'/ 'soft' descriptors, it may be questionable whether engineering education can live up to its claim of producing engineers fit for purpose, for which *"[preparing] students for professional competence has always been the ultimate goal of engineering curricula"* (Denis Lemaître, 2006, p.45). Traditionally, a technical-analytical discipline, engineering also needs to take into account 'soft', people skills, and thus integrate the '–ics' of mathematics with the '–ings', as in team working, in order to provide modern society with engineers fit for practice (Matthew and Hughes, 1993). Besides fixed disciplinary identities, the' ways of thinking and practicing' include an attitudinal component, which is difficult to shape in a traditional approach of targeted instruction. This is more susceptible to influenced by teachers and the social context, also outside the classroom, to model professional and ethical behavior (Walther & Radcliffe, 2007).

On the other hand, industry's narrow focus on *practice*, specific performance and technical depth work against the espoused interest in interdisciplinary competences, which requires generic skills, technical breadth and ethics, and thus a focus on *education*, which incidentally is what universities are committed to. This gives rise to a tension between educating students in the subject matter in a deeper sense, and training them for the world of work or practice (Matthew and Pritchard, 2009). Transcending the disciplinary confines and pseudo-identities, e.g. 'hard'/'soft', might prove helpful in providing engineering graduates not only with professional skills, but also with the generic competences of 'graduateness', referring to "*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"* (Barrie, 2007, p.456).

The idea of learning through solving problems seems crucial for developing deep learning involving a focus on practice and various process competencies, i.e. meaning negotiations, team collaboration, communication, 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 working out their own learning objectives. The interdisciplinary ideal whereby knowledge is constructed organically is equally valued in PBL (Savin-Baden, 2007). One of the ways of implementing PBL is the problem and project based learning, which aims at exhorting deep and personal learning and promotes collaborative and project management skills (Kolmos, 1996). Meanwhile, it also carries the risk of limiting student's potential of expanding the range of learning to the type of assignment set by the project, as either task-, subject-, or a specific problem to be solved, with an excessive product focus (the project report). The more open the problem scenarios, which are central to PBL, the more they expand the scope of learning as they enable students to become active inquirers and treat knowledge in flexible ways. Still, it may be argued that project work and process competencies derived from teamwork and a joint focus on product may promote transferable skills to contexts of work. Interdisciplinarity might amplify student learning in both an educational and a professional sense by providing project oriented work with competing perspectives on knowledge, while attempting to animate PBL scenarios with the drive necessary to navigate the open spaces of learning and knowledge.

3 EMPIRICAL EVIDENCE

The data originate from the setting of an annually recurring, three-day-long digital building workshop, "Digital Days", DD, which takes place in Aalborg, Northern Denmark, and brings together industry specialists, university and vocational training staff, as well as exponents of the entire range of professionals populating a building project. 80-100 students participate from three different educational institutions representing specific programs, all related to the construction industry and necessary actors to complete an entire building project. Examples of represented educations are Architect, Architectural Technology and Construction Management (ATCM), Craftsmen, HVAC Technicians, Indoor Environmental and Energy Engineers, Structural Engineers and Building Informatics specialists. The students are organized in two individual design teams divided into a number of groups representing the educational specializations as well as special roles related to the building project such as Building Owner, Project Manager, Model coordinator and Information Exchange Coordinator. The participants engage collaboratively on a common digitized design and collaboration platform based on the Building Information Modeling (BIM) method, in a real-life job situation, having to reach consensus regarding the final solution.

Building Information Modeling (BIM) is a method used in the construction industry to optimize and improve efficiency in building projects. It implies changes in both technology and processes, hence the way of working moves from linear processes where the actors are passing 2D drawings from one to another, towards integrated design and iterative design processes based on 3D models of the building including both geometry and other properties of the building elements. The aim of the technology is to support an efficient and partly automated information exchange between the actors as well as efficient model coordination and collision detection between models produced by the teams of different specializations. BIM alters the cross-disciplinary approach used in the industry today, since it is only possible if the processes are iterative and disciplinary contributions are continuously being merged into the project (Eastman et al., 2011). BIM both requires and supports interdisciplinary collaboration and it is suggested as a means to include interdisciplinarity in engineering educations (Sabongi 2009, Casey 2008). Perspectives and challenges of these integrated building design environments are further discussed by Christiansson et al. (2009).

3.1 Perceived effect of the interdisciplinary project workshop

The data stem from participant observation during the entire workshop, where the research team acted as process facilitators; informal talks with various working groups, especially the three groups of engineering students, at both undergraduate and graduate level. It also consists of participants' evaluation of the workshop and of the perceived value of learning by answering an online questionnaire. Additional evaluation meetings were attended, both with the engineering students, and with all participant groups, who shared their learning experiences and gave feedback on the workshop. Finally, a similar evaluation form was filled in by industry representatives, as well as a number of interviews and talks during the workshop. Within the scope of this paper, the data have been treated as a collected body of evidence, which has been examined in an interpretivistic manner through the lens of interdisciplinary collaboration.

At the end of DD the students filled out a survey that gave a sense of the perceived learning status on 14 different statements for both before and after the workshop, on a five point scale. 51 out of 83 students answered, 19 were engineering students. We focus on the highest/lowest ranked statements - before/ after DD. The statements that scored most *before* DD were: *"I have an increased interest in learning more within my professional area"* and *"I learn a lot from other people when we work in a group"*. The statements with lowest scores were: *"I have an insight in the competences of other professional groups"* and *"I am capable of grasping the various professional areas and see the connections between them"*. These statements support the fact that current university structures encourage disciplinary depth and work in homogeneous groups within single disciplinary fields. The students lack insight in other disciplines as well as knowledge about the interconnections between these.

After DD, the highest scores remained unchanged showing students' interest in becoming competent in their fields. However, the next highest ranked statement was: *"I don't hesitate when confronted with a new, unusual problem"*. This indicates that the students have gained more confidence in approaching problems. The lowest prioritized points after DD was: *"I can shift between being in charge and letting go of control"* and *"I have a considerable knowledge within my professional area"*. This doesn't imply that the students' skills diminished; it only indicates that they have evolved more in other fields. The low scores regarding the perceived knowledge within their fields may be related to the student-status, not yet fully knowledgeable, which also explains the increased interest in learning more. DD is a very different setup with a much more compressed schedule than the usual study groups and assignments, which forces the students to work faster and make decisions based only on estimation, which they are not used to. Similarly, the new ways of working and the pressure felt from other professions, which depend on their output, may cause a certain strain.

The students have *evolved most* regarding: *"I have an insight in the competences of other professional groups"* and *"I am aware of the elements which are part of the building process"*. They evolved least in: *"I learn a lot from other people when we work in a group"* and *"I have an increased interest in learning more within my professional area"*. This confirms that DD improve students' competences within the area of interdisciplinary collaboration, and give them an insight in the building process. On the other hand, the students don't evolve much in teamwork and interest in their own professional area, as they already ranked high before DD.

3.2 Gaining interdisciplinary collaboration skills

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 process of integration of the various disciplinary contributions during DD revolves around certain themes denotative of interdisciplinary competence. Among these, 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 contractors, really makes an impression"*.

Communication mediates the negotiation of common understandings:

"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 to interdisciplinary competence:
"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 great cooperation between all the different groups. Because of this workshop, I will be capable of working in a real life situation 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 educational programs? They should have some insight; it doesn't come automatically, with professional excellence"* (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"* (idem). The interviewee stressed that the interdisciplinary work form at the workshop corresponds to an evolving work organization, called "project houses", where all the specialist contributors are gathered synchronously during the initial stages of a large project. At the final evaluation meeting, the students maintained that the real interdisciplinary gains were made in the group meetings, where group leaders 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 for BIM offers a particularly appropriate framework for developing interdisciplinary competences: *"How suitable it is to store all data inside a drawing, which improves the cooperation between groups; and the different parts of the building process".* Regarding the problem based approach and collaboration skills in the workshop, students emphasize the stimulating effect of real life problems: *"All the different problems, the more, the better, because they create opportunities for having to cooperate with others"* and: *"We discover problems with methods and tools that we wouldn't get to know in school".* The need for trying out alternative solutions and 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".

Learning to handle uncertainty or re-assessing core analytical competencies is valued particularly by engineering students bound perhaps by a certain methodological rigidity: *"I concentrate on the type of knowledge that I can operate with 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".*

Regarding collaborative skills, the specific social context is particularly valued as a modeling factor and a strong motivation for engaging with complex problems 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 INTERDISCIPLINARITY AND LEARNING: WHAT ABOUT CURRICULUM?

The reported digital building workshop illustrates some key characteristics of processes that support the cross-pollination and integration of multiple disciplinary perspectives. According to student testimony, *"[t]his type of workshop has the potential to expand disciplinary and interdisciplinary boundaries"*. We will here discuss some underlying factors that foster interdisciplinary collaboration and what they suggest as possible avenues for deliberate action at curriculum level.

One of the salient features has been the aspect of collaboration between participants from adjacent disciplines, who not only benefit from working in a team, but also from the process of negotiating solutions with concurrent teams. In such processes, team-members work together in a way that moves beyond the mere distribution of tasks, to gaining insight in new fields and developing integrative solutions. Participants mobilize their communicative skills in order to uncover each other's "ways of thinking and practicing" and the underlying principles of specific disciplinary methods in order to distill the problem solving approach. The prerequisites of such activities in DD are a large, poorly structured problem field that the participants are forced to find a joint way to cut through. They contribute their specialties to a digitally supported interdisciplinary arena to serve iterative problem clarification and solution loops. The setup is a real-life scenario populated by valued professionals and specialists, who serve as role models facilitating an attitudinal shift towards an interdisciplinary mindset. The experimental learning climate boosts participants' spirit of inquiry and freedom to advance viable solutions to the open-ended problem. The dynamic social milieu promotes mutual commitment and motivation to comply with the constraints of a product oriented approach, where interdisciplinary collaboration is instrumental to project work.

Regarding the problem and project-based learning model, which has a clear interdisciplinary aim, our findings suggest that there may be further scope for interdisciplinary collaboration, at both intra-departmental and faculty level, and preferably within wider social contexts including the industry. The development of process skills explicitly aimed at through project work may similarly be limited by working in homogeneous groups on mutually agreed projects, with little scope for developing cross-disciplinary collaborative skills and abilities to negotiate conflicts, integrate expertise from related fields, and produce flexible, innovative solutions. The socially facilitated learning environment created by real-life problem scenarios and the coexistence of diverse disciplinary perspectives qualifies students to work in independent, interdisciplinary project teams, increasingly in demand by industry.
Meanwhile, the dominance of disciplinary thinking and subsequent engineering program configurations set structural limits to the implementation of fully-fledged project-oriented PBL-programs. In order to promote the development of interdisciplinary collaboration skills 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 the organizational and instructional levels, i.e. explicit ways of organizing interdisciplinary learning opportunities, as well as the competence development level, i.e. equipping staff with the required insight and tools to facilitate students' learning processes.

The consequence of taking a more marked interdisciplinary turn in engineering programs could be that interdisciplinary arrangements, such as DD would change status from an extra-curricular event to a fully acknowledged and accredited learning activity. Besides rewarding student and teacher interdisciplinary involvement, deliberate attempts should be made at institutional level to promote interdisciplinary activities. For instance, in the context of PBL, attempts could be made to establish interdisciplinary project networks for students to engage in, that could emulate the project-house work organization, evolving in industry. This could at the instructional level imply a new, interdisciplinary type of supervisor, equipped with specific competences to promote interdisciplinary thinking.

5 CONCLUSION

The digital building project presented in this paper has served to illuminate some core features of successful cross-disciplinary collaboration in the light of the increased interest from academe and industry alike in interdisciplinarity, i.e. the capacity to integrate multiple disciplinary approaches in problem-solving. The ideal of interdsiciplinarity is constrained both by current university structures favoring disciplinary paradigms, and from industry side, by requirements for practice training and specialized knowledge. The various forms of problem and project based approaches employed in engineering education include interdisciplinarity, which may though be limited by traditional disciplinary boundaries. Arguably, process competences such as collaboration, communication, ability to negotiate conflicts are limited by working in homogeneous groups on mutually agreed projects, with little scope for developing cross-disciplinary collaborative skills and ability to produce flexible, innovative solutions. Interdisciplinary collaboration opportunities offer viable problem-based scenarios for deploying students' competences in socially facilitated contexts spurring the spirit of inquiry within the field of open-ended real life problems.

The aim of this paper has been to raise awareness of inconsistencies surrounding espoused claims on interdisciplinarity at policy and implementation level and, based on the derived principles for successful cross-disciplinary collaboration, suggest a framework for integrating interdisciplinary collaboration skills into existing problem and project based learning curricula. Central to this turn would be to introduce interdisciplinary competence as a specific learning objective in the curriculum, to be pursued accordingly at the organizational and instructional level by appropriate strategies and incentives, amongst which the specific competence development of staff.

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