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MULTI-, INTER- AND TRANSDISCIPLINARITY IN CHALLENGE-BASED ENGINEERING EDUCATION

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ABSTRACT

Challenge-based learning (CBL) offers students in engineering programmes an opportunity to develop communicative and collaborative skills, apply disciplinary knowledge and develop boundary-crossing competencies. Mono-disciplinary approaches to CBL are generally regarded too limited, but whether multi-disciplinary, interdisciplinary, or transdisciplinary approaches should be used is open to discussion. Often, these concepts are used interchangeably, but there are notable differences. In literature, knowledge integration is mostly mentioned to make a distinction, but because of difficulties in applying this concept to education, we focus on tangible differences in educational practices, related to learning objectives, assessment, and the design of challenges. The different forms of CBL are illustrated by three case-studies carried out at a research university in the Netherlands. We found similarities, but also some subtle differences between multi-, inter- and transdisciplinary approaches to CBL. Multidisciplinary CBL projects are relatively pre-structured, with an indication of the knowledge that is to be applied, deepened, or combined. Interdisciplinary CBL is more open-ended, with students made responsible for connecting their disciplinary backgrounds to the project and for integrating disciplinary

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perspectives. Transdisciplinary CBL focuses more on impact than on integrating disciplinary contributions. Challenges are open-ended from a content and stakeholder perspective, while structure emerges in the interactions between students, teachers and stakeholders. Which form of CBL can best be employed in a course or programme is dependent on the intended learning objectives. Educators should be aware of trade-offs and of the specific teacher competences required to design and support these different forms of CBL.

1 INTRODUCTION

Challenge-based learning (CBL) is gaining popularity as an approach to engineering education. By working in groups on authentic, wicked problems of real-world stakeholders, students can develop transversal competencies and learn to apply disciplinary knowledge and skills in the analysis and solution of complex engineering problems [1] [2]. If supported well, students can also develop competencies to cross boundaries between academic cultures and disciplines [3]. Challenges, which are often related to Sustainable Development Goals, are complicated and require the involvement of several disciplines. Mono-disciplinary approaches to CBL are still used frequently [2], but the incorporation of different perspectives is generally considered to lead to richer and more creative ways of tacking societal challenges [1]. However, there is less consensus on whether multi-disciplinary [1] [2], interdisciplinary [4], or transdisciplinary [5] approaches are to be employed in challenge-based education. The terms are often used interchangeably, but on closer inspection there are notable differences. These relate, for instance, to how far students go beyond their disciplinary knowledge base, to knowledge integration, and to societal stakeholder involvement [6] [7]. In this paper we will explore how multi-, inter- and transdisciplinarity are different and how these differences show in challenge-based engineering education. The different approaches to CBL will be illustrated empirically by case-studies from a research university in the Netherlands.

2 CONCEPTUAL BACKGROUND

To distinguish between multi-, inter- and transdisciplinarity, education literature often refers to knowledge integration [6] [8]. In multidisciplinary projects students divide problems into components which they solve through disciplinary means, without any substantive integration of their approaches. The integration of disciplinary views and the arising of new, combined perspectives remain limited. In interdisciplinary projects, students do integrate knowledge from different academic disciplines. Transdisciplinary projects go a step further in integration, breaking down disciplinary boundaries and incorporating knowledge from ‘non-academic’ practioners and local stakeholders. In studies on interdisciplinary or transdisciplinary education it is noted that knowledge integration that pervades the whole process, from challenge definition and theoretical models to the choice of methods and proposed solutions. This integration complements processes of bringing in disciplinary insights, critical reflection and establishing the purpose of a project [6].

However, the concept of ‘knowledge integration’ is not without challenges. Pinpointing it empirically is difficult [9]. It is embedded in various activities of a complex problem-solving process and can often only be identified indirectly through reflections and explanations of participants [8]. Besides, the integration concept appears to assume a unification of models, approaches, etc., in a coherent whole. This oversimplifies the iterative, emergent and diverse ways in which fields of knowledge may interact in problem solving and learning processes. In these interactions, there may be all kinds of misfits, conflicts and incommensurabilities, especially when knowledge from engineering disciplines is being combined with that of social science, humanities and (non-academic) stakeholders. The process may then be better characterized as tinkering and bricolage [10] than as integration and synthesis. Given these complexities, disciplinary knowledge integration and the kind of novel combinations this entails may be beyond reach in student projects. Furthermore, interdisciplinary and transdisciplinary ways of working have their own models and approaches [11], which go beyond the integration of models and approaches of separate disciplines.

In this paper we will not focus on the somewhat elusive concept of knowledge integration to distinguish between multi-, inter- and transdisciplinary CBL, but look at differences in educational practices, showing for instance in learning objectives and problem-solving processes, to characterize these distinctions for educational purposes. Typical for *Multidisciplinary* CBL projects is that they start with the identification of the disciplines of participating students. Learning objectives are primarily related to the application and deepening of disciplinary knowledge in a complicated context and to the development of skills to collaborate and communicate with other fields of expertise. To be able to reach these objectives, decomposition of the challenge along disciplinary lines is important. Final products contain different disciplinary parts, which are aligned and aggregated in an overall solution. To avoid marginalization of certain participating disciplines, the challenges need to be designed or specified in such a way that all participants can reach their learning goals. This asks for careful alignment with involved stakeholders and limits the open-endedness of the challenges [12].

Alternatively, *Interdisciplinary* CBL projects start from more open-ended, unstructured, ‘real-world’ or wicked problems, which are more loosely coupled to the disciplines of participating students. Learning objectives are primarily related to collaborative teamwork and other transversal skills [4], less to the deepening of disciplinary knowledge. Students also learn to identify new knowledge they need for tackling the problem. Solutions may include disciplinary parts, but students work actively on synthesizing or linking these. Stakeholders are involved as challenge owners, who bring in the problem, provide information and feedback, and to whom the solution is being presented or ‘sold’ [12]. Student teams act as problem solvers [13] and as interdisciplinary problem-solving goes beyond their disciplinary training, scaffolding by teachers is crucial [4].

In *transdisciplinary* CBL, an extra layer of complexity is being added. Stakeholders are seen as part of a heterogeneous learning community rather than as challenge owners. Challenges, processes and solutions are being co-created by students, teachers and (multiple) stakeholders [14]. The problem-solving process is focused on societal impact or transformation rather than on the application of academic models or techniques [7]. This implies that students' learning goals highlight the development of societal collaboration, communication, co-creation and other boundary-crossing skills. They also learn to deal productively with situated knowledge and input from non-academic sources [15]. Interdisciplinary scaffolds are being complemented by scaffolds targeting understanding and collaboration across academia-society boundaries [16]. Table 1 gives an overview of the different characteristics.

Table 1: Characteristics of multi-, inter-, and transdisciplinary educational practices.

	Multidisciplinary	*Interdisciplinary*	*Transdisciplinary*
Learning objectives	• application and deepening of disciplinary knowledge in a complex context • collaboration and communication with other disciplines	• identification and use of new knowledge from various academic sources • collaboration and teamwork across disciplines • transversal cognitive skills	• identification and use of new knowledge from academic and non-academic sources • collaboration and teamwork across disciplinary and societal borders • impact oriented skills
Challenge design	• relatively prestructured • carefully balanced disciplines	• open-ended • loosely coupled to participating disciplines	• open-ended and ambiguous • loosely coupled or not coupled to participating disciplines
Problem-solving	• decomposition along disciplinary lines • alignment and aggregation of disciplinary contributions	• synthesizing and linking disciplinary contributions	• bricolage of disciplinary and non-disciplinary contributions
Stakeholder involvement	• providing challenges that are carefully aligned with learning objectives	• providing challenges that are relevant for their practice • providing information and feedback on	• providing challenges that are relevant for society • co-learning, co-creating, co-assessing

		process and product	

3 METHODOLOGY

To get a better understanding of how multi-, inter- and transdisciplinary approaches to CBL work in practice, they will be illustrated by three case-studies of educational modules, carried out at the University of Twente in the Netherlands. Table 2 gives an overview.

Table 2: Overview of cases

Approach	*Case*	*Involved Disciplines*	*Level*	*Kind of module*	*# ECs*
Multidisciplinary	Consumer products	Industrial Design, Mechanical Engineering, Industrial Engineering	Bachelor	Mandatory course	15
Interdisciplinary	Science to Society	Various technical and social sciences	Bachelor	Minor module	15
Transdisciplinary	Shaping Responsible Futures	Various technical and social sciences	Master	Extra-curricular programme	30

Data were collected through semi-structured interviews with module coordinators, teachers and participating students. Besides, study materials (such as project assignments and rubrics) and products of the challenge-based projects were collected. Educational prospectuses, course manuals and module pages hosted on the learning management system provided further sources. For this concept paper, a comparison was made on the basis of data on learning objectives, assessment, and design of CBL projects. These elements provide a first idea of the differences in educational practices.

4 RESULTS

In the description of the learning objectives of the three cases the terms multidisciplinarity and interdisciplinarity were used to a large extent interchangeably. The multidisciplinary module even talked about ‘interdisciplinary teams’, while the interdisciplinary and transdisciplinary modules used ‘multidisciplinary teams’ to describe student collaborations. However, there was a difference in the composition of student teams. In the multidisciplinary module ‘Consumer Products’, students from three bachelor programmes participated and each team included participants from these different backgrounds. In the interdisciplinary case ‘Science to Society’, which is part of a minor, the involved disciplines varied over the years and over the teams.

Students self-enrolled in teams and were encouraged to mix gender, disciplines, etc. The extra-curricular transdisciplinary ‘Shaping Responsible Futures’ also included varying disciplines. However, as it was selective the coordinators could steer on heterogeneity of the influx. Students formed their own teams as long as these represented the disciplinary, gender, cultural variety. Learning to communicate and collaborate in these teams was a learning objective in all three cases.

When regarding the learning objectives of the cases there was clear overlap, but when looking more closely, two differences became apparent. First, in the multidisciplinary module the application and combination of disciplinary knowledge was much more specified (*Integrate and employ knowledge from different fields of expertise (like marketing, styling, CAD/CAM, intellectual property, packaging, production, supply chains, research methodology, etc.),* while the interdisciplinary and transdisciplinary modules left this open. The interdisciplinary and transdisciplinary cases dedicated seperate learning objectives to integrating knowledge and needs (*Composing requirements that integrate the needs of different stakeholders and different domains*) and to transcending disciplines (*Transcending disciplinary perspectives in creative, systemic and responsible designs*) respectively. A second difference was that the latter two more strongly emphasized stakeholder engagement. In the interdisciplinary case this was phrased as collaboration and communication with stakeholders, in the transdisciplinary case as boundary crossing (*Collaborating and communicating across disciplinary and social boundaries*).

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When regarding the rubrics used to assess the final products of the CBL project there were also subtle differences between the cases. In the multidisciplinary project rubrics, the terms ‘coherence’, ‘multiple dependencies’ and ‘balance’ were used to describe how contributions of the three involved disciplines and of the sections in the report should be related. A high score, for instance, was for final reports in which “*the sections are very well balanced and of high value. A wide range of mutual dependencies and important consequences is correctly presented*.” In the interdisciplinary project, the student disciplines varied and it was up to the students to integrate their disciplinary contributions. According to the rubric, a good project ”*includes all the disciplines present in the group and integrates them optimally, using supporting literature*” and “*the most relevant requirements from various disciplines are present and nicely integrated into a coherent requirement specification,…*” Stakeholder interaction was also part of the assessment. The result should “*reflect frequent and clear collaboration with the target group and the problem provider*”. In the transdisciplinary case, a single point rubric was used to provide feedback on the final product. It stated that the presented innovative solution should be “*clear, well-argued, original, transdisciplinary, realistic, with potential to contribute to SDG, based on academic literature and other sources*”. There was no reference to the specific disciplinary contributions of the participating students. Extensive engagement with different kinds of stakeholders was also valued in the transdisciplinary assessment rubric.

When looking at the design of the challenges and the problem solving process, there were also differences. In the multidisciplinary case students went through specified stages of a product development cycle (*from portfolio analysis, via market research to the presentation of mock-ups and manufacturability*) to develop a consumer product. They interacted with a real-world customer and had autonomy to develop a solution within certain boundaries. In the interdisciplinary case, the challenge and process were more open-ended. Students could choose a challenge and a client based on their interests. The end product was a prototype of a product, which would be further developed in a subsequent module. The transdisciplinary case was even more open-ended, in terms of framing of the challenge, design process the form of the final product. Scaffolding was provided, but to a large extent the challenge and process were shaped along the way by students in interaction with teachers and stakeholders, inspired by ideas, models and theories brought in by the different participants. Stakeholders were approached as co-learners, sparring partners and as starting-points to connect to the broader societal field.

5 DISCUSSION AND CONCLUSION

In this paper we explored the differences between multidisciplinary, interdisciplinary and transdisciplinary ways of shaping challenge-based engineering education. Rather than taking the often employed but somewhat elusive concept of knowledge integration as a starting point for distinguishing between multidisciplinary, interdisciplinary and transdisciplinary CBL projects, we focused on differences in educational practices. These were exemplified in learning objectives, assessment rubrics and designs of challenges and CBL processes. We do not deny the relevance of knowledge integration, but approach it as embedded in multi-faceted, context-specific, social processes of learning and teaching rather than as the outcome of a more abstract process of disciplinary aggregation, synthesis, or transcendence.

In our study we found clear resemblances between multi-, inter- and transdisciplinary approaches to CBL, but also some notable differences. The challenges and CBL process in multidisciplinary projects were more pre-structured, by teachers and stakeholders, with a careful balance between the contributing disciplines. There was a clear view on which knowledge was to be applied, deepened, or combined, which was reflected in learning objectives and assessment rubrics. Interdisciplinary challenges were more open-ended, offered choice, and gave students the responsibility to link their disciplinary background to the project. Integration of disciplinary perspectives was expected and assessed. Transdisciplinary projects were open-ended from both a content and a stakeholder perspective, meaning that neither the framing of the challenge nor the stakeholder constellation were fully set beforehand. Structure emerged along the way in the interactions of students with teachers and stakeholders, and there was no obligation for students to apply ‘their’ discipline. The relevance of the output was valued over the disciplinary input. Learning objectives were formulated at a more abstract level and rubrics were open to tailored evaluation and feedback.

It may be tempting to regard transdisciplinary projects as the ultimate form of CBL, as they take on the most complex and ambiguous challenges, have the richest student-stakeholder interactions, and are most strongly impact-focused. However, challenges can also be approached in multidisciplinary and interdisciplinary fashions. It depends on the intended learning outcomes of the courses and programmes. Educators should be aware of trade-offs (what is won in open-endedness may be lost in disciplinary depth) and of the different teacher competences needed to design, organize and scaffold these different forms of CBL. Interdisciplinary and transdisciplinary CBL also require the teachers to cross boundaries and get out of their disciplinary comfort zones. Engineering programmes may consider to offer their students multi-, inter- as well transdisciplinary forms of CBL in their curriculum, in order to provide them with richer learning experiences needed to prepare for jobs as professionals or researchers in a complex society.

This paper offered an exploration and illustration of three different forms of challenge-based engineering education. This is meant as a first step. Further conceptualization of multi-, inter- and transdisciplinary education is needed. Also the empirical analysis is to dive deeper into the communalities and differences in educational practices and learning processes. What do student actually learn from these different kinds of CBL, how can they deal productively with the different kinds of knowledge and how can teachers effectively scaffold the more open-ended processes? These pressing questions ask for further research.

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