ABSTRACT

TU/e innovation Space offers an environment for students to work in interdisciplinary teams on societal problems. These problems ask for development of a shared language for interdisciplinary collaboration and to facilitate learning processes. Little is known about design characteristics for these problems, and what is needed to support interdisciplinarity in student teams. The educational concept Challenge-based learning (CBL) uses authentic societal problems ('challenges') to urge student learning. The main research question for this case study is: What design characteristics of innovation Space challenges support interdisciplinary student collaboration? Data collection consisted of analysis of learning materials, interviews with teachers and students, student surveys about motivation and collaborative learning in four courses and two honour’s tracks. The results show how teachers ask for competence development in supporting students, especially in assessing and integrating discipline knowledge. Students reported high motivation combined with anxiety for open and complex challenges. Over time this anxiety decreases, as students develop knowledge to solve the challenge. Students also reported a need for a clear mapping of learning goals to activities and assessment. For students it appeared often unclear how and on what criteria they are assessed. Yet, students also reported support in developing ownership, self-directed learning, and collaborative learning. This study confirms existing literature that emphasises difficulties in students developing rigorous discipline

1 Corresponding Author A. van den Beemt, a.a.j.v.d.beemt@tue.nl
knowledge in CBL and interdisciplinary assessment. This study increases our understanding of challenge design and how interdisciplinarity can be situated in this design. It offers starting points for research on motivation and collaborative learning in CBL.
1 INTRODUCTION

1.1 Challenge-based learning in higher engineering education

Today, many universities are embracing the concept of ‘challenge-based learning’ (CBL), to better prepare students to contribute to societal challenges. CBL is an interdisciplinary experience where learning takes places through identification, analysis, and collaborative design of a sustainable and responsive solution to a real world – authentic - sociotechnical problem [1]. These authentic problems, also known as 'challenges' are seen as self-directed work scenarios in which students engage [2]. The goal of these challenges is to learn how to define and address the problem and to learn what it takes to work towards a solution, rather than to solve the problem itself. The final deliverable can be tangible or a proposal for a solution to the challenge [3].

At Eindhoven University of Technology in the Netherlands (TU/e) CBL has been introduced in a bottom-up approach by allowing teachers to experiment with a variety of implementations. The result is diversity in characteristics of CBL between courses and departments, giving a local colour to CBL. Many of these experiments are conducted in the context of the award-winning TU/e innovation Space. TU/e innovation Space offers an environment that encourages and facilitates students to work in interdisciplinary teams on challenges that directly impact our world [4].

The working definition for interdisciplinarity in education science that studies of Interdisciplinary Engineering Education (IEE) seem to agree on is that interaction between fields of expertise requires some level of integration between those fields to count as "interdisciplinary" [5]. Interdisciplinary interactions can be considered as attempts to address societal challenges by integrating heterogeneous knowledge bases and knowledge-making practices, whether these are gathered under the institutional cover of a discipline or not. Sometimes integration is facilitated through students striving to incorporate foreign methods and knowledge into their own practices, and sometimes collaboratively through interdisciplinary student teams. Generally individuals operate in interdisciplinary teams and learn from others' perspectives and produce work in an integrative process that would not have been possible in a mono-disciplinary setting [6]. The end result is that team members develop a shared language for collaboration and interdisciplinarity to facilitate learning processes [7]. This language should be shared among stakeholders, including students, teachers, and industry or NGO’s.

However, little is known about characteristics that make societal challenges suitable as assignment, and what should be done to support interdisciplinarity in CBL, including how to structure challenges and whether or how to control the space of possible approaches to a challenge students should consider. Furthermore, current courses and projects appear insufficient in their support of interdisciplinarity as part of the student learning process, as intended in the TU/e innovation Space educational vision/philosophy. This paper aims to address this lack of knowledge by investigating support for interdisciplinarity in CBL-assignments in TU/e innovation
Space courses and projects. We do so by exploring innovation Space challenges with the purpose to find a shared language that supports interdisciplinarity in engineering education.

The core research question is: **what characteristics of innovation Space challenges support interdisciplinarity and student participation in those challenges?**

This research question can be divided into sub questions:

- How does interdisciplinarity emerge in innovation Space projects and courses?
- How can challenges in innovation Space projects and courses be characterised?
- What motivates students to undertake CBL activities?

Given the aim of this paper, we focus on collaboration and integration as operationalization of interdisciplinarity [7], and open-ended versus structured as operationalization of challenges [8].

## 2 METHODOLOGY

### 2.1 approach and included courses

To understand which characteristics of challenges support interdisciplinarity in CBL, an evaluative case study method was chosen. Evaluative case studies can be defined as enquiries into an educational programme, system, project, or event to determine its worthwhileness, as judged by researchers, and to convey this to interested audiences [9]. The context for the current case study is an extensive educational innovation initiative focused on development, implementation, and evaluation of CBL at a Dutch university of technology.

The included courses aimed at implementing CBL in interdisciplinary teams, with students working on assignments in close interaction with high-tech companies and societal organizations. They combined the design and engineering of a product, service, or system with new business development. Defining and refining of a problem and ideas for a solution simultaneously and iteratively through analysis, synthesis, and reflection processes were important elements of these courses. Students needed to iteratively experiment on ideas through visualization, prototyping and testing until a feasible problem-solution fit emerged. This means that students had to communicate with experts, potential clients, and end users as part of the validation process. Students were in charge of their own project and encouraged to think out-of-the-box to develop a feasible and valuable solution.

### 2.2 Data collection

Data collection consisted of learning materials, three interviews with individual teachers and coaches, four focus group interviews with three to four students each, surveys about student motivation and collaborative learning (N = 67), and course-evaluations of five TU/e innovation Space courses, including two honour's tracks.
2.3 Instruments and analysis

In addition to analysis of course materials and student evaluations, semi-structured interviews with teachers and coaches were held. These interviews focused on how teachers and coaches approached interdisciplinarity in student teams in their course, and how they supported and assessed the learning process. Focus group interviews with students focused on how they perceived the design of the course, the degree of interdisciplinary interaction, and the support of their learning process.

Analysis of interview results was guided by sensitising concepts (interdisciplinarity, integration, collaboration, structured vs open-ended, group-learning, anxiety and motivation) that were derived from the theoretical background. These concepts were used to categorise answers from interviews, focus group and open-ended questions. The categorisation was validated by the authors, by continuous discussion and evaluation. To increase the reliability of this qualitative analysis, the authors collaborated closely in the process. Points of debate and uncertainty were discussed until consensus was reached.

Motivation and group learning were measured with the nine-item version of the intrinsic motivation inventory [10], and the dimensions of social learning framework [11][12].

3 RESULTS

3.1 Interdisciplinarity in CBL Courses

Collaboration

Interdisciplinarity is analysed here as the ways in which collaboration and integration are required and scaffolded. In general the five included courses show a high level of support for collaboration, for example because teams are composed on an "interdisciplinary basis" (courses 1 and 2) at the start of each course. Furthermore, the learning goals and assessment show how students develop the ability to contribute and work in a team: “Develop skills in cross functional communication and cooperation” (course 2). Most often these learning goals are assessed with individual reflection (e.g., the honors tracks) or peer-review tasks (course 2). Issues of team-performance, organization, and direction are most often addressed in weekly team meetings with the coach (honors tracks, courses 1 and 2) or workshops (course 1).

Existing literature shows how engineering students are in need of clear signposting and scaffolding, especially for open-ended and complex assignments [7]. Team development in the included courses is scaffolded through multiple (non-summative) instruments, such as mini-pitches, weekly team-member scores, and Agile project plans per week.

Integration

The results show how teachers to a certain extent experience implementing interdisciplinarity in their course or project as problematic. Teachers also reported a need for competence development in supporting students, especially in assessing and integrating discipline knowledge. For most of the courses this is reflected in
learning goals addressing problem-solving instruments and targets that are largely
given by one disciplinary framework. Still, students were encouraged to be open and
creative, and assess each other’s value. But in only one course specific workshops
were addressed to interdisciplinary team building. In one of the honour’s tracks, the
course coordinator required students not to work as islands. Students should
understand each other’s work but not to a high depth, however, they needed to be
able to explain to each other what they were doing – their intent and plans.

The criteria for learning goals on integration in the included courses show difficulty in
measuring the level of integration. For example, in course 1, assessment criteria for
integration evaluated students in terms of how well they "Identified, envisioned and
promoted explicitly the role and contributions of different engineering disciplines.
Demonstrated and explained convincingly how knowledge and skills from all different
fields were considered in the designed system." This puts weight on the engineering
disciplines; however, it stays unclear what is meant with ‘explicitly’ and ‘convincingly’.
Still, it does demand that students with more than one engineering group think about
the role of their different technical fields in the project.

Integration is sometimes defined in learning goals as “synthesis”. For example:
students will “Develop a problem-driven, creative and integrative design, resulting in
an original and validated prototype that balances desirability, feasibility and viability.”
(course 1). It is thus expected that the prototype will at least score well on each of
those three categories. However, none of these goals or criteria give any real solid
meaning to what could be meant by integration here, except the ability to produce a
design which scores jointly well on viability, feasibility and desirability.

That said, an interdisciplinary project outcome is expected to emerge by virtue of this
set-up, even if it is not a form of interdisciplinarity necessarily governed by the
bachelor degrees of the students. Further, although interdisciplinarity is not a
learning goal in any of the included courses, students were required to make sense
of concepts relevant to the challenge, from their own disciplinary perspectives. This
is overall a kind of integrative task.

3.2 Type of challenges

Open-ended vs structured

In three of the courses the challenges appeared open-ended. However, the targets
students were meant to hit are mostly described with disciplinary frameworks, and
thus structured rather than strictly open-ended. For example, in course 1 a
framework of technical feasibility, business viability and customer desirability meant
that students did not have complete freedom with respect to how they could frame
their approach. Technical feasibility weights towards an engineering-based
assessment, and business viability towards a business-science based assessment.
Customer desirability leaves options for students to bring in different perspectives
from fields like psychology. Each three were separately built into the learning goal
“Analysis” as distinct requirements. “Analysis” requires students to be able to
analyse their problem from each of these different points-of-view and make a distinct
case for each. In course 2 groups were mixed and it was a learning goal that students, “Develop skills in cross functional communication and cooperation.” However, students were expected principally to make a business case and follow structured tasks for doing so.

For three courses “challenge” in sense of CBL seem to be interpreted in practice mostly as the challenge of commercialization of technologies. This suggests a potential inconsistency with how CBL is commonly envisioned, namely as a means of prompting students to explore all kinds of societally relevant approaches and solutions to societal problems. In practice there can be a bias towards business-based solutions, when for instance other social sciences (or natural scientific) approaches may be preferable or even necessary for effective societal solutions.

The two honour's tracks allow students freedom in taking an approach to the challenge. After students decided upon an approach, they have to familiarize themselves with it if necessary. This is supported by workshops (e.g., research design methods; qualitative/quant research; prototyping; graphic design courses; professional skills courses) on relevant topics related to the subject of the challenge, and through meetings and students' personal-development plans (including plans for knowledge acquisition).

3.3 Student motivation

Students reported high motivation combined with anxiety for open and complex challenges. Over time this anxiety decreased, as students developed knowledge to solve the challenge. Students also reported a need for a clear mapping of learning goals to activities and assessment. For students it appeared often unclear how and on what criteria they would be assessed. Yet, they also reported support in developing ownership, self-directed learning, and collaborative learning.

Regarding social learning, the students showed a hands-on attitude rather than a learning attitude. They appeared focused more on solving day-to-day hassles than developing and working on a team learning agenda including personal learning goals (see also [11] and [12]).

4 DISCUSSION

This paper explored how interdisciplinarity can be supported in courses that are based on the educational concept of CBL. We focused on collaboration and integration as aspects of interdisciplinarity, and open-ended versus structured to characterise challenges.

Regarding collaboration, the results suggest the need for attention to equal division of disciplines in team selection. However, this in itself is not enough to ensure interdisciplinary engagement. This is confirmed by students who reported to be in need of support in bringing disciplines together and learning to speak each other's language. This can be done by weekly team meetings with a coach, and designated workshops. Finally, it is advised to make interdisciplinary collaboration part of the
learning goals and assessment, for example with individual reflection or peer-review assignments [7].

Teachers appear in need of competence development especially on assessing integration and integrating discipline knowledge, and on supporting students in integration and synthesis. Integration can be scaffolded by activities that emphasize the relevant contribution of single disciplines to the challenge, for instance by discipline pitches given by individual team members.

With respect to interdisciplinarity overall it is not suggested that students need to produce a novel or unique methodological approach which goes beyond their existing disciplinary frameworks. However, it appears better to ask students to explain how each part might have contributed to improvement in other parts.

Whatever approach is chosen, it is important to make clear to students how integration will be assessed [13]. The challenge for teachers is to clarify basic concepts for interdisciplinarity (“synthesis, integration etc”), define them in practical rather than abstracts terms, and make clear to students how to satisfy them.

If integration of both engineering fields and non-engineering fields, such as entrepreneurship, are in the learning goals, they should be mentioned explicitly in assessment criteria, to avoid biases with respect to what kinds of integration students think of as important or necessary [14]. If interdisciplinarity is to be a learning approach then there needs to be incentives for students to think about integration. Assessment is a relevant tool here for creating such incentives.

Deeper assessment of interdisciplinary skills can be made by asking students individually at some point in the course to represent their understanding of the other fields in their groups. This would encourage them to seek out this knowledge from others, and explain its relevance. Further to this -more in the line of formative assessment- students could be asked to perform perspective-taking tasks on problems – by being asked to explain themselves how other fields might address or perceive the task.

From our results it can be concluded that challenges need not necessarily be fully open-ended, although it is important to avoid conflicts between expecting students to contribute their expertise, but then largely constraining them to use instruments and methods from just particular fields. If interdisciplinary collaboration and integration are goals or expectations but all the tasks are geared just towards a limited set of fields, then this risks frustrating students who are not from business science. As such it appears more important that students have ownership of the problem/challenge and have control over it, and that this ownership is well supported and scaffolded. Scaffolding can be done by encouraging students to cross boundaries themselves and take on different roles and developing different expertise. This potentially allows students a much deeper insight into interdisciplinary work, by gaining the perspective of how others using other methods might think.

Motivation for working on challenges appeared high in this study. However, this was combined with anxiety for the challenge and stakeholders. The result could be that
students develop a hands-on attitude, rather than a learning attitude, by focusing on daily hassles of the project. It is suggested to support students in developing a learning attitude by helping them develop and reach individual and team learning goals.

This study confirms existing literature that emphasises difficulties in students developing rigorous discipline knowledge in CBL and interdisciplinary assessment (see also [8]). The results contribute to our understanding of challenge design and how interdisciplinarity can be situated in this design. It offers starting points for research on motivation and collaborative learning in CBL.

REFERENCES


[7] Author, xxxx


