2023-10-10

# Varieties Of Project-Task Design In Interdisciplinary Engineering Education

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# Varieties of Project-Task Design in Interdisciplinary Engineering Education

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***Conference Key Areas**: Addressing the challenges of Climate Change and Sustainability, Contributions on other topics in Engineering Education*
***Keywords**: Interdisciplinarity; project-based learning; challenge-based learning; problem-design*

*ABSTRACT*

Experience in interdisciplinary problem-solving is considered crucial if engineers are to be equipped to handle modern complex environmental and sustainability challenges. Such challenges cross disciplinary boundaries. Project-based learning is currently a central paradigm for providing that experience. Teams from different disciplines are formed to work together on a specific scientific or engineering project-task (often a real-world inspired problem). Furthermore according to the paradigm projects should be open-structured to allow students to experience interdisciplinary problem-solving as it might occur in the real world. In this study we explore preliminary results of data collected on 5 project-based modules at a Dutch technical university. We find that despite the preference for open-structure advocated in educational research the modules differ in terms of how structured they are, with the majority structured in a substantial way. In these cases the instructors design their project tasks to meet both institutional objectives and also to afford interdisciplinary interaction between students. We examine the motivations behind the design features they employ, and also some of the drawbacks based on student feedback. This study points the way to further research but should help build awareness of different design option and their tradeoffs.

# 1 INTRODUCTION

Interdisciplinary skills are widely seen as necessary for training real-world problem-solving abilities amongst engineers and scientists. In education, the development of such skills is often closely identified with project-based learning, and in turn, with projects designed around open-ended or open-structured problems [1],[2],[3]. Open-structured problems are meant to simulate authentic problems in which few constraints are set on potential solutions [4]. Students from different disciplines form interdisciplinary teams to find solutions to these problems. In the process it is hoped that students will develop skills relevant to working across disciplinary boundaries. Given the expectation that real world problems are generally not resolvable within current disciplines, students have incentives to experiment with new unfamiliar methods, and to acquire disciplinary perspectives outside their own, in order to fashion more optimal solutions [5]. At the same time interdisciplinary problem-solving is difficult, and open-structured questions can present real challenges to students who are not used to working together and for which problems are complex [7],[8].

Our preliminary investigation sought to answer the following research questions, 1) to what degree are projects in interdisciplinary project-based courses open-structured (given the prevailing view on open structured designs), and if not, how are projects designed; 2) what are motivations for various design steps with respect to supporting interdisciplinary education. To address these we investigated interdisciplinary project-based modules at a technical university in the Netherlands.

# 2 METHODOLOGY

## 2.1 Research Background and Questions

Open structrured or “open-ended” project tasks are problems designed with minimal constraints on how to interpret a problem, what methods to use to produce a solution, or what a solution should look like [9]. For such problems the problem-space is large, inviting many possible approaches and solutions. A central educational principle underlying PBL and PjBL (and CBL) is self-driven learning. Self-driven learning favors students having the responsibility for developing a solution to maximize their own ability to learn independently but also to think critically and reflect on their own knowledge and its limitations [5], [10]. There is a strong belief that real-world problems increases student motivation as a result [11].

Opposed to these are highly structured problems problems. These include many explicit or implicit constraints which narrow down the problem space, placing restrictions on which approaches to use, and funneling students towards only a small set of desired solutions. In between these two extremes lies a spectrum of designs each with varying degrees of structure. In an open-structured case, for instance, student teams may simply be asked to formulate a project task themselves in teams leaving it completely open how the problem is chosen and how it is formulated. Alternatively, specific project tasks may be presented by instructors or external parties, but still allow students to have control over how to interpret those tasks and solve them. In general, to qualify as open-structured, the task-descriptions should not seek to prescribe the approach students should take nor set strong constraints on a solution, or what the problem-solving process should look like [2].

Analysis on problem-design for either project-based or problem-based learning, interdisciplinary or not, is not extensive in general, at least in comparison to research on other aspects of project-based learning [12]. Nonetheless research has been done categorizing and framing the various considerations that should go into problem design generally [5], [13], [11]. Most substantive in this regard is the work by Hung and his collaborators to put together a holistic framework for problem-design in the context of PBL: the 3C3R framework [7], [11]. Within the 3C3R framework Hung and his collaborators suggest many important factors which govern problems over which designers have control. Interdisciplinarity is briefly mentioned in one paper as a factor of problem structure, but otherwise not considered by Hung nor to our knowledge in any other problem-design discussions.

### 2.2 Approach

To study these questions we have taken a case study approach; investigating five “modules” at a technical university in the Netherlands. This university’s core educational model is structured around project-based learning modules, consisting of multiple cohesive courses feeding into group projects. Some of these modules are interdisciplinary, i.e. that students from different faculties converge within the module, and work together in interdisciplinary teams for the duration of the project. Course and project design decisions are the responsibility of the instructors, such as whether to run the project over the duration of the quartile, apply it as a capstone, and which accompanying courses to implement.

**Consumer Products (2nd year module):** This bachelor module couples mechanical engineering, industrial engineering & management as well as industrial design students. 50% of the module is allocated to an interdisciplinary project-based design task, which is provided by an external client. Assessment is measured by the ability of the team to meet the external client’s requirements, as well as how they integrate knowledge from different disciplines.

**Discrete Structures & Efficient Algorithms (2nd year module):** This module pairs applied mathematics and computer science students. 20% of this module is allocated to a collaborative project at the end of the course. The project task is to produce an algorithm which can successfully test the isomorphism of certain graphs.

**Modeling and Analysis of Stochastic Processes (2nd year module):** This bachelor module involves students from applied mathematics , civil engineering , and industrial engineering & management . The module provides various sub-courses training students on various aspects of stochastic modeling, culminating in a final two week interdisciplinary capstone project called the “multidisciplinary project”.The goal is provide a hospital a schedule management systems, and result are assessed in terms of how effective and usable they are, but also how well components from different disciplines are integrated.

**Autumn Challenge (open):** The Autumn Challenge is an extra-curricular challenge-based learning elective, open to students of all disciplines affiliated with the European Community of Innovative Universities (ECIU). It is open to 3rd year bachelor and master students. Students collaborate across disciplinary boundaries on a challenge provided by an external party (e.g. business, government agency etc), and develop a solution through contact with the challenge provider, and the support of a tutor. Projects are partially assessed in terms of how well different disciplinary views are considered and synthesized in the result.

**Science2Society (3rd year modules):** Science2Society is part of the High Tech Human Touch minor programme; available to all students at the university. The minor programme allows students to take courses outside their bachelor programme in the first semester of the third year of their degrees. Similar to the Autumn Challenge, Science2Society students select problems provided by external groups (businesses, government agencies) to work in multidisciplinary teams. Students decide individually which challenge they would like to work on. Projects are also partially evaluated according to whether topics in multiple disciplines are explored.

For each case study we collected student survey data, semi-structured interviews with instructors, and course materials. In this study we rely particularly on course materials, which describe the project-task structure and criteria used in its assessment. Principally we examined project task descriptions and criteria collectively to assess whether any statement connected to the project set a constraint on what would be a good or valid project outcome or approach. Instructors were Interviewed on their design choices, to corroborate the intentions of such statements. Finally, we apply student survey data to reflect on aspects of those designs. For the Consumer Products, Discrete Algorithms and Science2Society this data derives from surveys we designed on students' interdisciplinary experiences and views on interdisciplinary education as a result. Students from consecutive groups were surveyed (2019/20 and 2020/21 groups). Response rates varied but track was kept of the disciplinary backgrounds of students and how frequently students from each discipline responded. Autumn challenge students were given a similar survey but just for the 2020/21 group. With respect to the Stochastic Processes module, we rely on standardized university course evaluation suveys from 2014/15 to 2017/18. These surveys included questions on interdisciplinarity and space for written feedback on interdisciplinary experiences.

## 3 RESULTS

### 3.1 Open-closed design elements

Of the courses we analyzed only the Autumn challenge task was purely open-ended in its design, meaning that interdisciplinary groups had the freedom to frame the problem they wished to solve (in consultation with a task provider); as well as how they would pursue it, what kinds of tasks they would each perform and what solutions would look like. The other modules employed a mix of structural elements in their project-task design; goal structuring, process structuring, problem balancing and modularity. They did so for a variety of reasons; at least partially to facilitate interdisciplinary interactions between their students, ensure constructive alignment. Table 1 describes the distribution of these design structuring elements.

*Table 1. Types of structuring found in project based learning case studies.*

| Case study<br>Structuring type | Autumn Challenge | Science 2Society | Consumer Products | Algorithms | Stochastic Processes |
|---|---|---|---|---|---|
| Goal structuring | | ✓ | ✓ | ✓ | ✓ |
| Constraining problem-solving | | ✓ | ✓ | ✓ | ✓ |
| Problem balancing | | | | | ✓ |
| Problem Modularization | | | | | ✓ |

Here we describe briefly these types of structuring and their motivations:

**Goal structuring**: Most of our modules set specific constraints on the outcome of the project either through the description of the problem and its targets, or via the assessment criteria. An extreme example of this is the Algorithms module. The problem goal set for applied mathematics and computer science students to solve collectively was a specific graph isomorphism problem. This kind of problem requires teams to construct an algorithm which can correctly infer whether two graphs are isomorphic; a very particular well-defined goal.

A problem can be otherwise open-ended but still subject to this kind of structuring. In the Consumer Products module for instance the main task is somewhat an open-ended design task. The problems are given to students by clients to design a product based on a loose set of goals. These problems are supposed to be relatively open-ended in the sense that students can go in numerous possible directions based on their own assessments of what a good outcome should be. The module however does set some requirements on what the students need to produce, as well as how the design is to be evaluated, which naturally directs students towards looking at certain sets of solutions rather than others. Chief amongst these for instance is the need to have entrepreneurial or marketable design solutions. This constraint is not a neutral one. It narrows the sets of choices students need to consider.

Goal structuring was used according to course designers for a number of reasons in these interdisciplinary modules. Firstly, in the Algorithms and Stochastic Programming cases goal structuring was primarily a result of other institutional goals which needed to be taken into account for implementing interdisciplinarity in existing programmes. In these modules a primary goal was training students in specific mathematical and programming abilities required within their bachelor programs. As such the task needed to be designed to ensure students would exercise these abilities. Goal structuring was a means to channel students towards doing so. In certain cases however defining goals can direct students towards learning objectives that stimulate good interdisciplinary problem-solving, such as entrepreneurial skills for refining engineering design. In either case however the goal structuring serves to scaffold and direct interdisciplinary relationships towards specific goals rather than leaving it to students themselves to navigate.

**Constraining problem-solving approaches:** In addition to setting limits on what counts as a good solution, projects were also structured in our cases by limiting the “problem-space”, namely constraining the set of methods and approaches students should consider. This included setting limits on the specific variables to be studied or by giving data of a particular kind. Some of these were introduced in the project-task context by training students in specific methods that could be practised and applied directly within the challenge. This is a feature of both the Algorithms module but also the Stochastic Processes module. In the latter the project forms the last two weeks of the module. Before that, students receive two courses in various types of mathematical methods. During these short courses students do small project tasks. Students are told that their answers can form the basis of their response to the capstone project. In this way students are guided in the set of choices and methods they need to consider in the design of the hospital waiting list management system. This kind of structure can be quite implicit however. The Science2Society case is framed by the instructors as open-structured problem-solving but the problems are nonetheless implicitly structured. One challenge given to students was to study how AI and big data can improve social housing. This question prioritized methods from computer science and gave priority to the capabilities of those methods.

As with goal structuring these design aspects play a dual role. They also direct students towards developing a specific set of skills, required by individual programmes, such as the application of algorithms to mathematical problems. In the Stochastic Processes case however these limitations were employed to reduce the challenges for students of finding an integrated interdisciplinary solution, given the instructors already had the desired solution in mind. Sub-tasks within the challenge, were designed to fit the skills and interests of participating disciplines. This did not preclude different methods being applied to each sub-task, nor how information should be precisely integrated but it did channel students towards a subset of the overall problem-space which contained integrable interdisciplinary solutions.

**Problem balancing:** The Stochastic Processes project-task was, as explained to us in interviews with instructors, designed over several iterations to fine tune and balance the contributions between the different disciples involved. The goal was to ensure that the components to which each group would contribute were roughly similar in terms of the time, energy, degree of intellectual contribution prescribed in the problem; as well as the meaningfulness or relevance of the individual task for each group. In the first iterations of the Stochastic Processes module the project task was not well-balanced – the project could be solved without a solid mathematical contribution. In written feedback in the course evaluation surveys mathematics students reported feeling redundant, and mathematics students evaluated the project lower than the other groups. In 2014/15 for instance mathematics students evaluated the project at 5.3 out of 10 (53% response rate) compared to 6.0 for the other groups (response rates 40%). In response the module coordinators attempted to redesign the project-task to specifically incorporate a mathematical component.

**Problem modularization:** Lastly a particular feature implemented in the Stochastic Processes task in order to facilite interdisciplinary interaction, is modularity. The project was designed to be decomposable into separate problems which are optimally resolved using methods from specific disciplines. This should not be taken to imply that the problem was simply constructed as separate discrete problems with no interconnections. Rather the required interconnections were not so complex or uncertain so as to prevent disciplines solving their parts effectively. This served to cut down interdisciplinary problem complexity and shift emphasis onto integration. In the Stochastic Processes students are given the following task description:

*You are hired by Hans Bakker (a hospital administrator) to provide insight into the following aspects: 1)The effect of the number of resources on the waiting times of patients. This insight should be useable by the hospital management to make a trade-off with the financial implications. 2) The design of an efficient and patient friendly appointment making strategy, where patients are directly informed about their appointment time……. 3) The design of an estimation procedure to provide patients with relevant information regarding their departure time from the hospital.* (Case description 2014)

The first bullet point is geared towards the business students and their previous model training in economic analysis, the second and third bullet relate towards both civil engineering and mathematics students. The civil engineering students are meant to cover the traffic modeling aspect, the mathematicians to apply a mathematical approach to estimating hospital waiting and processing times. Students have to integrate their components into a complete working tool. With these integration goals students need to coordinate their activities to ensure their functional components can interact and exchange information on a technical level.

### 3.2. Risks and Benefits

Based on the data we collected some brief preliminary observations can be made, which might help instructors consider what might be the best options in their case. With respect to deciding whether to pursue an open versus closed design generally, one statistic was reported by students in the Autumn Challenge case, which was not reported in more closed cases (such as in the Science2Society module). Students were asked to compare the depth of project outcomes based on these interdisiplinary open-structured versus what they would produce in a normal disciplinary project. A majority of the Autumn Challenge students (9 of 11; 25%

response rate) reported either lower depth or equivalent depth but less depth than they expected. This points to one issue that project-task structuring is trying to address, namely that open-ended problems can create less opportunity for students to engage in technical work (what we might call the “back-end” of a problem), since much time is invested in formulating a problem and negotiating roles (the “front-end” of a problem). Any form  of task structuring, reduces front-end struggles and moves students closer to working on the back end, by scaffolding their initial choices. This is important for interdisciplinary courses seeking to train specific methodological skills.

However the implementation of structure did in our cases introduce trade-offs affecting how modules were perceived by students. Introducing goal or problem structuring risked importing disciplinary biases into the modules. This was not necessarily evident to instructors, as mentioned in the Science2Society case. In this module students formed groups before selecting problems. Some students found themselves in groups in which their skills were not relevant. Structuring can also be explicit. In the Algorithms case, the work required of all students is explicitly computational; mathematics students commented poorly on this fact in surveys, given their role was superfluous and the work could be left entirely to the computer science students. Hence framing tasks structurally risks itself creating biases which then need to be addressed. Open-structured problems may largely avoid such problems, particularly if students are asked to select their own problem. Students in the Autumn Challenge for instance were less likely to see it as important that they were given a fair disciplinary role compared to other roles (14 of 14; 35% response rate). But there are reasons to believe that even largely open problems may nonetheless be unbalanced. When instructors set open problems some formulation or description of the problem and its goals may be necessary to adapt them to the disciplines involved in the programme, or to fit the themes of the course. While it may not be always obvious, problem descriptions can restrict problems in ways which prioritise types of solutions over others, and in turn, types of disciplines over others.

A second issue is artificiality or potential loss of realism. This is perhaps most acute in the case of problem-balancing, in which the goal is in effect to generate an artificially balanced problem. In the real world problems are unlikely to arrive balanced. For instance in the Stochastic Processes course students are asked to build an online appointment tool which takes into account both hospital processing times, but also car parking and travel times. This gives a role to civil engineers, who learn traffic modeling, but is not a realistic request. A hospital administrator is unlikely to be interested in having a system which works so specifically door-to-door for patients. These moves have consequences. Some civil engineering students in written feedback did cite this negatively, consistent with the theory that overly artificial problems can affect student perceptions of educational value and motivation [6], and lessen the chance to acquire skills relevant in particular to grappling with the uncertainty of real world problems.

Finally it can be very hard to design meaningful interdisciplinary project tasks if the instructors themselves have had little experience of integrative interdisciplinary work, and thus have no sense themselves of how to coordinate and integrate methods across disciplinary boundaries. Instructors in the Stochastic Processes module reported the difficulty of constructing a balanced and modularized problem, given primarily a lack of experience working together, but also given the different institutional objectives with respect to the learning objectives each discipline had for their own students. It took several iterations before they were able to find a reasonable balance which was still not perfect at the time of our study.

## 4 SUMMARY

In this paper we report on an initial investigation of project-task structure in interdisciplinary modules at a Dutch technical university. We find that most structure their problems – despite a prevailing view on the need for open-structure for interdisciplinary education. We outline the types of structuring and examine the motivations for each, and risks, which emerged during our study.

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