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Scaffolding interdisciplinary project-based learning: a case study

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ABSTRACT
Can you ask students from three different bachelor programmes to help solve planning and routeing problems for hospitals? In the presented case an interdisciplinary approach was shown to be successful after some redesign. Students from Applied Mathematics, Civil Engineering and Industrial & Engineering Management jointly designed solutions for 'traffic' to and through the hospital using stochastic modelling. Importantly this project was scaffolded through coursework, supervision and problem-design. The particular scaffolding strategy employed by the teaching team offers other teacher teams ideas for making interdisciplinary project-based learning a more effective learning opportunity. At the same time we need to ensure that students feel at home in their own programme and will be empowered to work with other specialists.

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Interdisciplinarity; project-based learning; scaffolding; teacher teams

1. Introduction

Project-based learning or PjBL is often applied for the development of interdisciplinary problem-solving skills in science and engineering education. In a recent review of engineering education literature principally concerned with interdisciplinary training (between 2005 and 2016), approximately two-thirds of the 99 included papers, analysed or proposed either a problem-based (PBL) or project-based (PjBL) learning context (van den Beemt et al. 2019). Project-based learning (PjBL) offers student teams an authentic, engaging, and complex problem for which they have to design a solution or artefact based on data collection, assumptions and further inquiries. Students apply and integrate concepts and procedures while improving professional skills (Repko, Szostak, and Buchberger 2017). We will also refer to problem-based learning (PBL) which aims at the learning of concepts and procedures through well-chosen predefined authentic situations. PjBL method was developed for the medical field first (Barrows and Tamblyn 1980) and then applied to many other settings. While PjBL seems to have obvious affordances for training interdisciplinary skills, such as providing opportunities for creatively designing solutions for open problems and exercising team skills that include working with other specialists, there are reasons to be cautious about simply transplanting what might work well in disciplinary learning contexts to interdisciplinary ones. We follow Stentoft (2017) in raising specific challenges with respect to the use of interdisciplinary problems in PBL that we also find applicable to our PjBL case, using these to argue that PjBL requires some scaffolding. We illustrate what such scaffolding might look like using the example of a course constructed at the University of Twente. This course of 15 ECTS[1] credits (=420 h) combines traditional coursework, modelling cases and an interdisciplinary problem-solving project for second-year Industrial and Engineering Management Students, Civil Engineering Students and Applied Mathematicians. The course and

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project problem are carefully designed to funnel students towards collaboration, and class evaluations suggest that students do score the module well in terms of its interdisciplinary goals. The data suggest that students do produce integrative solutions and collaborate robustly despite their different backgrounds. However at the same time many students report ongoing problems, which point to some essential difficulties modules which are scaffolded in this way face. Using the data of this module we analyse the elements of module and problem design which we believe contribute to this success, and at the same the basic institutional and cognitive challenges such designs must deal with.

2. Design aspects for interdisciplinary project-based learning

Interdisciplinary skills are widely seen as an essential goal of modern scientific and engineering training across a range of disciplines, such as medical and environmental disciplines. Modern medical and environmental problems cross disciplinary boundaries. Such problems cannot be dealt with, with both the depth and sensitivity required, using the methodological tools of one discipline alone. They require interactions among groups of scientists and engineers who are often not used to working with each other, such as sociologists and engineers, or ecologists and economists, in order to integrate their often diverse knowledge, approaches and scientific resources (e.g. models, data, experiments etc.). There is thus an imperative for education scholars to (1) provide a good conceptualisation of what skills and learning goals are required for good interdisciplinary work, (2) provide education strategies and resources that meet these learning goals which instructors can draw from, (3) provide solutions that can help overcome institutional constraints which commonly restrict the development of collaborative programmes. In this paper we are concerned with all three aspects, each of which intersect in the context of our case study.

The design of interdisciplinary PjBL often centres on authentic 'real world' problems as the starting point of projects (Repko, Szostak, and Buchberger 2017). The complexity of these problems is such that team effort is required as well as the integration of knowledge from different domains and the application of different engineering practices (Lansu et al. 2013; Lattuca, Knight, and Bergom 2013). For interdisciplinary settings the course design can either require homogenous student teams to cover and integrate all relevant angles or require students from different disciplines to jointly analyse the problem and then design solutions. For teacher teams a similar situation exists, either interdisciplinary researchers or engineering professionals can run the PjBL course or a team of teachers with different backgrounds can together supervise the learning processes (van den Beemt et al. 2019). On the constructivist view of learning, the control of the learning process is mostly transferred to the student teams. Their joint and individual struggle should help them gain the skills that they need for interdisciplinary settings. The open-ended or open-structured nature of the problems allows for more creativity (Rhoten, O'Connor, and Hackett 2009). Through PjBL, students should realise that real-world problems are more than merely solving exercises with the right set of equations.

As such it is not hard to see why PjBL would seem an intuitive option across a range of different interdisciplinary learning goals. For instance for those who conceptualise ID in terms of soft or professional skills the collaborative environment of an interdisciplinary project seems highly desirable. Direct interaction with others outside one's field confronts students with the necessity of developing such skills in order to communicate and discover meaningful modes of integration, certainly to a greater degree than might be experienced within a field. For those who conceptualise the requirements for ID in terms of meta-cognitive skills (Ivanitskaya et al. 2002), again, PjBL seems ideal. An environment in which students are faced with, and forced to work with, students with different sometimes opposed conceptual frameworks and methodological presumptions should force them to reflect on the nature of these presumptions, and ultimately develop a 'meta-disciplinary' awareness. Rather than focussing on content learning of a single discipline, PjBL puts the problem to be solved first (Sternberg 2008). This creates space for students to transgress disciplinary boundaries in the search for solutions.

However while there is much well-motivated enthusiasm for PjBL in scientific and engineering training, there are reasons to be cautious about what students can actually gain from open-ended collaborative problem-solving tasks when it comes to ID. Importantly we do have to be aware of the difficulties of ID, and the manner in which these exceed the difficulties of ordinary within-discipline problem-solving. Repko, Szostak, and Buchberger (2017) and MacLeod (2018) have researched crossing border contexts in order to identify the kinds of challenges researchers face or what techniques researchers have developed to overcome these. And while certainly students do not face the same kind of institutional challenges (stemming from disciplinary peer review and promotional systems) they will face similar cognitive challenges.

Of course if such problems are challenging at the ID research level, then assigning the same kinds of challenges to students (and even their teachers) should provoke a certain hesitancy. If experts do not succeed readily in collaborative interdisciplinary tasks, can we really expect students to? Redshaw and Frampton (2014) interviewed students after an open-ended interdisciplinary collaborative based scenario project. Students found coordination difficult by virtue of the mass of different possibilities given the ill-structured nature of the scenario they were given.

> Scenarios presented were very broad in scope due to the nature of the multidisciplinary subject and many students struggled with this, finding that they were not sure where to focus their efforts, or feeling that they had not gone into enough detail for MSc level work as they'd had to cover such a large topic. (Redshaw and Frampton, 2014)

In general students felt like they lacked both guidance and various constraints they could work with at the outset, which affected their motivation and ability to participate in any deep way in an interdisciplinary process. Further if the faculty guiding the course do not themselves have relevant interdisciplinary experiences or have limited commitment to ID then they themselves may be of limited help (Gardner et al. 2014). This points to a deep structural problem of interdisciplinary learning in general. Faculty responsible for interdisciplinary programmes are often recruited from specific disciplines because of their disciplinary, rather than interdisciplinary, expertise. Among other things this creates problems for assessment insofar as such faculty generally only feel competent to assess disciplinary contributions rather than the quality of work according to interdisciplinary goals, like integration. Fragmented assessment along each teacher's competencies may lead to fragmented student team activities steering away from integration goals.

These difficulties advocate against the use of unscaffolded PjBL for training interdisciplinary skills. If the goal is for students to have a reasonable chance of engaging in productive self-directed learning through which they might gain the professional and meta-cognitive skills then educators need to think in greater depth about how to facilitate this. Stentoft (2017) argues specifically that students need to have clearer learning signposts, where what is wanted from students in terms of meta-cognitive skills for instance, needs to be more visible to students in the curricula and in learning activities. It is important to manage students' expectations and give them a realistic sense of what the challenges are, but also concepts for thinking and reflecting on what skills they are relying on and developing in the process. Stentoft suggests that teachers themselves need to play a more active hands-on role than they might in a disciplinary context.

> … the tutor (facilitator) must address a number of processes, for example, supporting a groups' establishment of a constructive learning environment, utilising students' prior knowledge to facilitate new knowledge construction, facilitating a process enabling students to work in-depth with the problem and to structure their knowledge in a meaningful way, supporting student reflections, and facilitating and stimulating students' collaborative processes. (Stentoft, 2017)

All these interventions can undoubtedly help students gain more out of an interdisciplinary problem-solving context. However while these can support self-directed learning, none of these will necessarily help if the nature of coordinative and integrative problems students face are too difficult to start with. We want to suggest that more attention thus needs to be paid to the issue of how problems should be structured for interdisciplinary PjBL tasks, and how these problems should be integrated with the background course work and technical skill acquisition from which students ultimately need to draw their problem solution. To illustrate this we turn now to our case study.

3. Case-study: modeling and analysis of stochastic processes

We introduce this case as an example of a scaffolded PjBL strategy. The module is titled 'Modeling and Analysis of Stochastic Processes', and is ostensibly aimed at giving students skills for modelling stochastic processes relevant to the individual fields of students participating in the module. Based on the empirical information we have collected we believe this module design provides a positive case with respect to achieving interdisciplinary education outcomes (Thompson Klein and Mitcham 2010) which others can learn from. It is worth pointing out that none of the instructors involved were familiar with academic discussions of multi- or interdisciplinarity, but were guided by their own intuitions and feedback from students via course evaluations. Our illustration and discussion of this case is drawn from course materials, several interviews with course instructors and four years of course evaluations.

3.1. The module details and interdisciplinary project

The module 'Modeling and Analysis of Stochastic Processes' covers an entire 10 weeks quartile of full-time education for second-year students civil engineering (CE), applied mathematics (AM) and industrial and engineering management (IEM). 2017/2018 is the fourth year the module has been run. The module is divided into three blocks and is shown in Figure 1.

Blocks 1 and 2 focus on delivering disciplinary-specific education on content and procedures, part of which though is shared between a pair of groups. In Block 1 (4 weeks) students from IEM and AM receive the same course on Stochastic Modeling. This block covers problem-solving using Markov chains, queueing theory and stochastic dynamic programming using examples relevant to IEM. From the mathematical perspective, this block helps train the general application of these mathematical approaches. At the same time civil engineers receive a more discipline-specific block on traffic management modelling. This overlaps slightly with the material IEM and AM students get in their first block, insofar as some aspects of queuing theory for instance are relevant to traffic management, but aims to build up other traffic modelling skills concerned with road and intersection design, which are not relevant for the IEM and AM students.

In Block 2, IEM and CE students receive a combined block entitled Simulation and Heuristics, exploring various computational options for modelling systems – such as discrete event simulation – and relevant heuristics for extracting solutions from such models. Here the focus is on

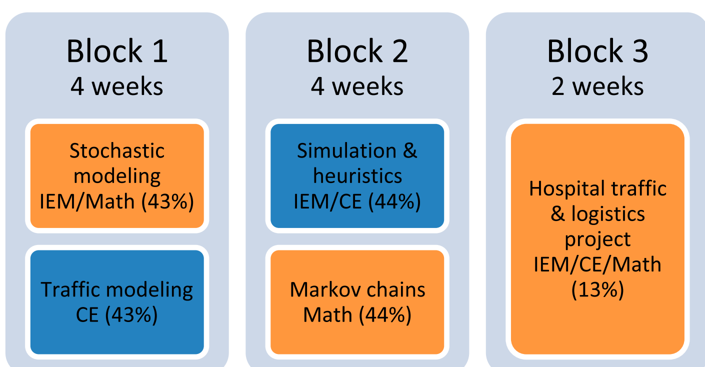

Figure 1. Block Structure of the cases study 'Modeling and Analysis of Stochastic Processes', based on course guide 2015–16. Student codes: CE = Civil Engineering; IEM = Industrial & Engineering Management; Math = Applied Mathematics.

computational techniques and skills. Such skills are useful for both traffic modelling and logistics. At the same time AM students receive a block deepening their knowledge of the mathematical properties and analysis of Markov chains working on mathematical derivations and proofs. This overall structure has not changed over the four years the module has been run.

These first blocks play an important lead-up role for the multidisciplinary project as we will explain. In interdisciplinary contexts engineering students have to learn to appreciate the way mathematicians think and operate by looking for familiar mathematical patterns, and establishing equations and proofs (Houston 2009). At the same time mathematicians have to understand that engineers engage in rapid-prototyping, sketching, reverse engineering and other practices, sometimes even before the setting is fully clear (Lucas, Hanson, and Claxton 2014). As such students need to find some common ground and perceive the added value in each other's skills which is necessary for multidisciplinary teams to feel that together they can do more than by an approach based on just one discipline. The challenge is to create a project design which facilitates this.

Here we describe specifically the 2016/2017 and 2017/2018 multidisciplinary project (MD project). The learning goals of the MD project of the module are a mix of professional skills and technical disciplinary skills. They are listed in the module guide as follows:

(a) *Communicate* and *collaborate* with students of different educational backgrounds;
(b) *Select* appropriate modelling tools (from the set of tools provided in this module) for a large real-life problem, and use them to *model* and *solve* the problem;
(c) *Interpret* the outcomes of the before mentioned tools and *formulate* practical recommendations for system improvement;
(d) *Inform* and *convince* the problem owner by means of a report and presentation. (their emphasis)

The communicate and collaborate requirement is rather vague, as it often is in ID courses, but the instructors have some particular concrete requirements in this respect – namely that students must utilise materials from each respective discipline in their problem-solution and reporting. Students are split into groups with proportionate representations of students from each discipline. The MD project involves a common problem handed to all groups. The problem is one of hospital clinic design and organisation. Specifically the students are told that the director of a newly built orthopaedic clinic wants to evaluate the possibility of using a dynamic planning methodology for scheduling patient appointments given three constraints: (1) Patients are directly informed of their appointment time; (2) Patients get advice on an appropriate departure time from home; and (3) during the routeing through the hospital, the patient is informed about the expected departure time from the hospital. Students are in turn asked to provide some specific results, namely (1) an appointment strategy that takes into account patients' time-dependent travel times to/from the hospital and the time required for parking; (2) an analytical approach to support dimensioning decisions (construction rooms, staff and parking area); and (3) an analytical approach that can be used to support online appointment planning. From these tools students are asked to propose specific interventions to hospital management. Apart from some data on arrival and treatment rates provided to students, and these constraints, the problem is open-ended.

Students have two weeks to complete the project, which puts students under a significant time pressure. Each group is responsible for their own project management. Students must keep a logbook of their daily activities, decisions, conversations and report the status of their project to their supervisor, one of three instructors for the project (one from each discipline). Students are required to submit a technical report describing the interventions with the computer code used to produce the main results. They are asked to give a presentation to hospital management of 20–30 min with specific improvement suggestions derived from their modelling. Students receive a grade according to the efficiency and creativity of the solutions proposed in the management presentation; correctness of the underlying models and how well they help verify proposed solutions (also observed in the technical report, and running the students' computer programmes); the value of the conclusions to stakeholders (tested through the presentation); finally, how well the group succeeded in using all expertise within the group (examined in both contexts and the logbook). The last requirement is a specifically interdisciplinary goal.

The module has altered somewhat over the four years since it was introduced. The rule that all expertise must be integrated in the project-solution was implemented after the first year (2014/15), and the problem was redesigned to necessitate this. Other modifications were made to the project for 2015/16 as instructors realised that they themselves needed to take a greater role in the supervision of the project. These interventions came about as there were major difficulties in the first year keeping all students in the project involved, particularly the applied mathematicians, due to reasons ultimately stemming from the initial problem design. However this lack of interaction fed somewhat clichéd impressions that mathematicians are difficult to work with and lack social skills. Students since the first iteration have been required to meet daily with supervisors to discuss principally how all students are involved, and get feedback and advice on whether the trajectories they are planning will enable integrated results. Further the deliverables or output students needed to produce from the project were adapted to ensure that applied mathematics content from the block 1 stochastic modelling component was essential, and clearly so, in order that the mathematicians could perceive how to be involved. This is an important point, since integration (which is often hard to assess directly or methodologically) can be measured in terms of how good and complete the project output is in providing useful and accurate information to the hospital 'door-to-door'. In this project in theory the IEM students apply a hospital waiting list model they acquired in block 2 and civil engineering students provide parking and traffic models they acquired in block 2, which then can be integrated to produce a general time estimate for patients, a time and cost-efficient appointment scheme which takes into account parking and traffic situations door-to-door. Mathematicians are supposed to contribute a dynamic programming and dimensioning methods for handling the optimisation processes both models require and creating a planning programme for hospital administrators.

The technical report (+ code) and the presentations are evaluated jointly by staff members of each participating department, who consult and agree on a final grade. Presentations are mostly graded on the basis of soft and professional skills, particularly the ability to communicate the results to the stakeholders, and back-up the results using technical arguments. In addition the validity of the students' results are assessed through an examination of the report, principally through examiners running the code themselves and checking robustness. As mentioned the degree of integration is not directly assessed, but is apparent in the ability to obtain reliable results which can effectively optimise the entire patient visit from door-to-door. The log-book for its detailed description of, and reflective on, the problem-solving process, focusing particularly on collaboration issues.

3.2. Evaluation questions and methods

To evaluate the effectiveness of the module different quantitative and qualitative methods were applied. For each of the questions at stake the sources used are shown in Table 1. For most

Table 1. Research questions and sources used.

Research questions and sources	Student evaluation score	Valuable aspect score	Student comments	Teacher observations and comments
RQ1 Do students appreciate the module?	X		X	
RQ2 Do students value the project?	X		X	
RQ3 Was learning to work with other disciplines achieved?		X	X	X
RQ4 Was application through modelling achieved?		X	X	X
RQ5 Was integration and interpretation achieved?		X	X	X

sources it was possible to compare the scores and remarks from the three collaborating disciplines, allowing us to check if the synergy strived for was perceived by all subgroups.

Student evaluation scores are derived from voluntary course evaluation surveys on a 1–10 scale. These surveys were collected over a four year period. Surveys were processed using optical reading facilties counting scores and scanning remarks of students. Average scores of 1.0–5.5 will be considered to be 'low', 5.5–7.0 'medium' and 7.0–10 'high'. The valuable aspect scores are derived from another question of these surveys in which students can pick multiple 'valuable project aspects' from a list. Items picked by 50% or more of the students are considered to be valuable. Student comments were harvested from two sets of questions in the student surveys; the first items asking students to identify strong points of the module overall and suggestions for improvement, and the second pair of items which asks students to identify more specifically strong points of the project and suggestions for its improvement. We have read all comments using a grounded approach to select a set of categories for grouping the comments which make similar points. These categorizations afforded us a rough quantitative measure of the frequency and thus relative weight of any particular concern or value amongst the students who replied. The vast majority of students only give one comment, and thus the answers are to some extent a record of what stood out as most salient for the students. Teacher comments were gathered through discussions with the individual teachers.

3.3. Module results

Currently the module is evaluated most positively amongst IEM students (Table 2), who awarded the module a 'top module award' at the University of Twente in 2016. Second are CE students with mostly medium scores. Applied Mathematics students are most critical in their evaluation. The AM numbers are low which might also be part of the story as they are outnumbered by the IEM and CE students.

Overall the module performs well with significant gains from the first to the second year (*t*-test, $p < 0.05$), and a 6.8 (max = 10) weighted average and standard deviation = 1.6 over the full period ($n = 249$), against the University of Twente average second-year module grade of 6.3 (Visscher-Voerman and Muller 2017). For IEM students this module is one of its highest ranking. However the module and project do not perform well amongst applied mathematicians and even appears to be dropping.

When asked to list strong points of the module, a total of 20 IEM students out of the 58 who responded across all 4 years of surveying commented that the module was well-structured and integrated (in most cases this was the only comment). Some IEM students seemed to realise an underlying design to the module structure. As one student put it, 'Strong construction by allowing the different projects and courses to take place sequentially. Projects also clearly took the theory along and integrated various topics. I have not often seen this in projects … '.

Some CE students cited structure and organisation as a strong point but at a lower rate (two or three per year out of an average of 17 responses per year). Only two AM students over the four years however reported structure as a strong point of the module.

Students of all groups across all years did cite working with other students or cooperation as a strong point of the module at a rate of about 20% of all comments across all year. Students otherwise

Table 2. Student appreciation of full module and final project (2014–2018).

Student discipline	Civil engineering (CE)				Industrial and engineering management (IEM)				Applied mathematics (AM)			
Year	14/15	15/16	16/17	17/18	14/15	15/16	16/17	17/18	14/15	15/16	16/17	17/18
Cohort (n)	60	69	53	75	71	102	106	111	17	17	30	32
Response rate %	40	48	53	33	40	31	19	24	53	47	33	31
Module Grade, max = 10	6.1	6.7	6.5	6.7	6.8	7.7	7.0	7.4	6.9	7.0	6.4	5.0
Project Grade max = 10	5.9	6.5	6.5	7.0	5.8	6.0	6.4	7.5	5.3	n.d.[a]	6.5	5.3

[a]No data (n.d.) due to this question being left-out accidently for this subgroup.

cited variously the applicability of the projects as a strong point, as well as a high level of challenge and the degree of learning, or specific module components and/or teachers.

Suggestions for improving the module show variation between the groups over the four year period. For instance responses amongst IEM students in the first two years single out the final project (6 out of 14 in the 14/15 survey and 7 out of 25 in the 15/16 survey) as a weakness for lack of clarity, added value or group size. In the 16/17 and 17/18 survey however the MD project is no longer the target of suggestions for improving the module, suggesting at least for IEM students the modifications to the project and additional teaching support were effective. CE students did not single out the project specifically but consistently felt that the module overall did not contain enough civil engineering content. For the module as a whole 5 out of 13 reporting students indicated that project tasks should contain more civil engineering to be relevant for their programme. This complaint was reported most in 16/17 (5 out of 14 reporting students). In 17/18 5 out of 10 reporting students indicated that the civil engineering aspect could be improved or as one student stated 'A parking garage is not very challenging'. AM students are even stronger in their response in this regard. In 14/15 6 out of the 9 students reported the lack of applicability of applied mathematics and the relevance of the block projects as a weak point of the module. As one student expressed it, 'there was no mathematics in it'. Also mentioned were the lack of guidance or support, the lack of time and too large project groups. Both problems were raised in 15/16 but too a much lower extent. Reflections of the AM teachers included that a revised assignment in Block 2 was too heavy and partly to blame for the lower appreciation in the last cycle of the module. At the same time the AM teachers also see that their AM students are not happy about the final project. For this they intend to improve their management of student expectations.

3.4. Evaluation of the interdisciplinary project work

Currently the vast majority of student groups pass this component (with a grade of 5.5 or more), almost all according to one instructor we interviewed (in this case the actual problem designer). From the instructor's perspective this is a direct indication that students invariably succeed in obtaining integrated results, and that his design succeeds in facilitating students' ability to produce such results. As he put it, his problem design 'fully accomplishes' integration.

Students were also asked to grade the multidisciplinary project (Table 2). Evaluations of the project have improved significantly from the first iteration of the course with an average appreciation grade from 5.8 (s.d. = 1.4) in the first year to an average 6.7 (s.d. = 1.6) over the next three years (*t*-test, $p < 0.001$). For mathematics students however results are somewhat ambiguous. While some improvement seemed to be occurring, the recent iteration of the course received much weaker reviews.

When asked specifically about the strong points of the project collaboration or cooperation was reported at a high rate: 22 of 49 IEM student responses stated this or an equivalent. 57 of 81 CE students gave this response. 17 of 23 AM students gave this response as well. Other high-frequency comments include that the project was an interesting case, it allowed them to experience real-time pressure, and allowed them to apply what they had learned. When asked for suggestions for improvement IEM students complained about the clarity of the project in 15/16. In 16/17 and 17/18 most of their comments are reserved for quality and availability of student assistants and the time pressure. CE students were not happy with parking cars as a task for civil engineers. Furthermore some CE students reported issues related to task division given group size or composition, for example 'In the end we did split up the tasks per discipline. Civil engineering students had to wait long to continue to work with the IEM results, and could do little in the meantime'.

Despite the modifications in the 15/16, 16/17 and 17/18 survey results AM students still reply frequently that they cannot effectively contribute to the project. 4 out of 10 students for 16/17 when asked what suggestion they might have for improving the project ask for a better role for mathematics students or more explanation or guidance for how they should contribute. This was the majority of comments in response to this question. The result are similar in 17/18. The thrust of their complaints in 16/17 and 17/18 are that the application of dynamic programming methods are too hard for the task, or that many assumptions are required which ends up producing a trivial problem. In the latter case students felt that their role lacked the substance of that of the other groups. 14 total comments for both 16/17 and 17/18 in response to both how the module could be improved and the weak points of the project took this line. In the latter category it was by far the dominant issue. For instance,

> Difficult for Math students to make a valuable contribution because DP model is too hard and must be too simplified to be a good appointment strategy (+ a lot different and more difficult than Block 1 project) and dimensioning can be estimated in a day using QTS+ which does not require knowing/understanding the formulas. What are Math students supposed to do, except giving comments, write technical report and do project management stuff? (16/17)

And another;

> The interdisciplinary project seems almost useless to Math students. There is basically nothing in the project that cannot be done by IEM or CE students. On the other hand, there are many things that Math students cannot do, such as making a plant simulation model or making a car park model (these things were already done by IEM/CE students and CE students respectively). … This means that I often felt useless to my project group, … .

As such mathematics students feel the problem is still not well-designed from their standpoint, and not affording them a sufficient role as experts in the project.

The students were also prompted to score valuable aspects of their project work by choosing from a list of options, with multiple options being allowed. This question was incorporated for the 2015/16 iteration of the course and onwards after the multidisciplinary project was revised. These directly survey target interdisciplinary learning goals of the project (Table 3).

Table 3 illustrates that most students from all fields considered the integration of subject applied in the project ‘valuable’. This is even true of the mathematics students who have the most trouble identifying their own role in the projects. Most found cooperation with other students also valuable. Results on whether the project was valuable with respect to applying previously acquired knowledge are clearly divided across the disciplines with a low score for AM students standing out significantly (*t*-test, $p < 0.01$). As mentioned in the case of the mathematicians the issue is likely that it is very difficult for them to apply the knowledge they acquired in their own specific second block of the course. The motivational effect and development of new knowledge were not among the targets of the teachers and do not score as well as some of the other aspects. Some students, most of all IEM students (*t*-test, $p < 0.05$), do feel they acquire new knowledge and insights, such as knowledge about the methods of those in their collaborating fields.

4. Conclusions and discussion

4.1. Conclusions on module and project related research questions

Our data collection and analysis in this case is limited, and not necessarily useful for extracting precise factors motivating student opinions. The data comes for the most part from somewhat standardised teaching evaluation surveys after all, and written student comments do not necessarily give a complex or exhaustive representation of precisely student experiences. Further response rates while average at least for voluntary student surveys are low and may be biased towards certain

Table 3. Project work as perceived by students, percentage of students scoring multiple valuable aspects (2015–2018). High scores (50–100%) in bold.

Student discipline valuable aspect	CE ($n = 86$)	IEM ($n = 79$)	AM ($n = 28$)
Application of previously gained knowledge	45%	**52%**	21%
Integration of various subjects learned in the module	**57%**	**71%**	**54%**
Development of new knowledge and insights	40%	**61%**	46%
Motivational effect	9%	14%	7%
Cooperation with other students	**64%**	**58%**	**50%**

opinions and experiences rather than representative. However given the statistical significance of certain results and the dominance of certain comments we think we can draw at least tentative conclusions with respect to our research questions.

4.1.1. RQ1 Do students appreciate the module?

We conclude that the course succeeds in giving most students a meaningful interdisciplinary educational experience. The module scores well overall against the University of Twente average and has improved its evaluations for most students. Comparing disciplines we see that IEM students score highest on the module, with CE and AM students scoring in the medium range mostly (Table 2).

4.1.2. RQ2 Do students value the project?

Improvements in the first two years have led to project appreciation scores going up for IEM and CE students (Table 2), although with AM students still not liking the project that much. The main goals of the project are also reported as strong points by the students.

4.1.3. RQ3 Was learning to work with other disciplines achieved?

Yes, definitely so. Most students across all groups clearly experience valuable collaboration with students outside their fields. This aspect was on top of the strong points mentioned by students from all three participating disciplines both in relation to the whole module and in relation to the project. This learning goal of the project was also picked by the majority of students as one of the valuable aspects (Table 3).

4.1.4. RQ4 Was application through modelling achieved?

Students score differently on this in the valuable aspect listing. Whereas the majority of IEM students do see this happening (Table 3), the AM students do not value this aspect as much as they report that too many simplifications had to be applied. According to the teachers who checked the modelling solutions of the student teams application was achieved.

4.1.5. RQ5 Was integration and interpretation achieved?

Yes. Most student teams succeed in providing an integrated solution according to the instructors. Students are able to link traffic models and information about travel times from civil engineering, to information about patient queuing and processes based on queuing models from the other fields. All subgroups in the student teams through their choice of the approach set some constraints on the other subgroups, by passing on specific information in terms of specific variables. Doing so requires explanation, interpretation and discussion. Students across all disciplines appreciate the integration aspect as being valuable (Table 3).

In the next two sections we consider in the first place what elements of the design contribute to the relative success of the module as a source of interdisciplinary education, and in the second place why the module does fail in certain respects and ultimately what the challenges are of implementing this kind of approach to interdisciplinary education.

4.2. Scaffolding techniques for interdisciplinary project based learning

Given these results our goal here is to extract the elements of the module design which help explain its relative success in generating collaboration amongst students in a PjBL framework. We believe the most salient of these elements are forms of scaffolding. One scaffolding feature, as mentioned, is the regular supervision of groups, an innovation introduced after the first year (Stentoft 2017). As one instructor put it one goal of these meetings is to prevent students from trying to formulate tasks in completely separate monodisciplinary ways and 'then going their separate ways'. The task students are set cannot be achieved this way (see below). The rest however stem from the way in which the problem is designed, and also how the problem is integrated with the rest of the module. Three main aspects of the problem design help explain the relative success of the project in cultivating interactions amongst students.

(1) The problem is framed to require contributions of specialist knowledge from all three groups, and is effectively unsolvable without them.
(2) The problem is relatively decomposable into disciplinary tasks which can then be reintegrated.
(3) The problem is solvable using project elements from previous module course-work (resulting in a relatively small choice set).

In practice all three help mitigate the essential difficulties of interdisciplinary research encountered in actual practices.

The first element was implemented after the first year, due to the applied mathematics students failing to identify a role for themselves. As mentioned in practice identifying a clear role within an interdisciplinary problem can be very difficult (as the instructors themselves discovered), particularly if a problem is framed in a way that is not conducive to identifying a role, such as a problem defined in another discipline's language or research agenda. Martin et al. (2013) have also reported on the importance of tasks which are balanced between contributing fields (see also McNair et al., 2011). This affects the confidence of different groups of students. For IEM and CE students the problem has been designed well in this respect. As mentioned above however mathematics students do not find the role marked out for them to be as clear, and although they were not explicit with respect to this, lack of confidence or sense of contribution may well have contributed to their negative attitude.

The second factor is related. Even if a problem can be identified, finding a means to decompose that problem into elements compatible with background knowledge and methodological capabilities can be very hard if boundaries or constraints within the problem itself are not recognisable from one's disciplinary perspective. Here the instructors build in relatively clear discipline-relevant boundaries for the students in the way they set-up and frame the problem. For example in the problem statement the following requirements are set:

Problem statement – *You are hired by Hans Bakker to provide insight into the following aspects*:

- *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*.
- *The design of an efficient and patient-friendly appointment making strategy, where patients are directly informed about their appointment time, which should preferably take place the next day (or the day after tomorrow). This appointment making strategy should account for a door-to-door process where we take the distance and time-dependent travel times of patients into account and advise them on a suitable departure time from their homes*.
- *The design of an estimation procedure to provide patients with relevant information regarding their departure time from the hospital. This estimate could at least be given upon arrival in a waiting room, but it would be nice to provide an estimate of the departure time from the hospital already when communicating the appointment time*. (Case description from course module 2014–2015)

The first bullet point is geared towards the IEM students and their previous model training in economic analysis of stochastic systems, the second and third towards both civil engineering students and mathematics students. Civil engineering students as mentioned are meant to cover the traffic and parking modelling aspect, the mathematicians to apply a mathematical approach to estimating hospital waiting and processing times. A decomposable problem avoids to some extent students having to develop novel methodologies. Indeed in practice in interdisciplinary research, researchers tend themselves to avoid having to do such a thing in any case, since it can be intensely difficult and may involve negotiating new evidential standards (MacLeod and Nagatsu 2018). Experienced researchers find ways of structuring or decomposing a problem in terms they can handle using their established tools even if this changes the nature of the problem. In this case students are not asked to do that work themselves. However this does not mean the problems are independent or that the appropriate methodologies to apply are obvious. Students arrive at the final MD project with their own different solutions to previous Block 1 and 2 problems which resemble the PBL approach with their emphasis on gaining procedural expertise through solving selected problems. Previous block groups are broken up to ensure the new group has a variable set of potential solutions. The PjBL task thus becomes one of together selecting between those previous problem-solving strategies, which best works amongst all on this particular task. This is not a trivial task and provides room for creativity. However students are explicitly informed that they should draw upon the methods and results from the rest of the module.

As a result overall the problem-space confronting students is simpler and more structured compared to the types of open-ended problem ID courses often handed out to students. By constructing a decomposable problem built around a set of already identified candidate methods, students face a restricted and well-determined choice. Their task is to evaluate in coordination with their team members, which from each discipline would succeed best at satisfying the individual problems and the overall goal, and then connect them together.

We think then this example serves to provide a model for problem-design in ID contexts, based on what we can take to be certain principles of ID problem design namely, contributive necessity, decomposability along disciplinary lines and a restricted choice set or problem space. Each of these reduce the complexities of interdisciplinary collaboration, and provide a better opportunity for students to experience at least some basic elements of interaction which finding themselves out of their depths. Additionally it is worth pointing out that this model is in line with T-shape thinking, by providing a model for integrating background disciplinary training with the development of interdisciplinary skills in a capstone project.

4.3. Accommodating barriers to interdisciplinary project-based learning

While we have represented the module structure as more or less effective for the goal of achieving some level of interdisciplinary interaction in a PjBL context, it is important at the same time to note the various difficulties and problems educators encountered setting up this structure, and to be circumspect about the degree to which such structures may be replicable in other contexts. This case identifies two main issues in this respect. In the first place achieving a problem structure which ensures that each disciplinary group will have an equally substantial contribution or role, and recognise that role, is likely to be very difficult, particularly when three groups are involved. Already the problem as mentioned is somewhat artificial departing slightly from a strictly 'real-world' problem in order to facilitate the roles of both CE and IEM students. As seen the problem in this case while it has been revised to accommodate mathematics students, is either perceived as too simple requiring students to generate a very idealised set of circumstances to apply dynamic programming too, or too complex, and impossible for them to resolve in any easy way. Mathematics students do not in fact find the projects they did in their dynamic programming course so helpful for defining their task in the context of the multidisciplinary project. Some CE students feel aspects of the problem are really not a canonical CE problem, and too far from their field to be worthwhile. We think this reflects on the difficulty of generating problems in particular which demand integrative solutions across three sources of expertise, but even across two sources can be difficult, particularly if the instructors have no sample or example problems to draw on from their own interdisciplinary experiences. Unlike real-world problems, educational problems for a capstone project aim to achieve balance in terms of contribution and complexity of the tasks at least relative to the number of each type of student in each group. It should be roughly equally accessible or scaffolded by what has previously been learned. Further finding a role for applied mathematics students is not straightforward, given that such students are often geared towards formal complex mathematical analysis in idealised scenario which a practical problem suitable for the level of engineers might not have. Structuring a problem which can satisfy not only the different subject matter but also different styles and values likely takes time and energy on behalf of instructors, and much trial and error.

However part of the difficulty of formulating such problems relates to the second main sources of challenges which are the institutional challenges of putting together programmes of education across multiple distinct disciplines. In general the institutional difficulties which constrain attempts to set-up interdisciplinary courses and curricula need further investigation (van den Beemt et al. 2019) and any proposed course or curricula design should be assessed with respect to such barriers, as well as what kinds of institutional conditions might better support or promote such designs. The module we have reported on here derives from a general demand placed on instructors by the University of Twente to exploit overlap between fields and bring students from different fields together.

This module is just such an attempt to do so. At the same time its structure was not necessarily entirely optimised for such tasks, but rather emerged as a pragmatic response to some deep institutional demands and constraints. The initial idea for the module was for it to be thoroughly interdisciplinary, with all students receiving the same technical material and interacting throughout. However the module was to replace separate disciplinary courses related to the area of stochastic modelling and simulation, which embodied distinct disciplinary educational standards and goals. Such standards and goals reflected what each discipline considers necessary to their own students' education. These needed to be reconciled, but this was not possible in a fully integrated way. For instance the mathematics team required that certain higher level mathematical skills relevant to stochastic programming could be taught (as part of training *as a* mathematician), which were inappropriate and too advanced for the others. However this module was the only space in the mathematics curriculum where such skills could be acquired. Adapting an interdisciplinary project to apply and extend the specific material and skills taught in this advanced area has proved very difficult, as we have seen.

Other issues likewise arose with respect to the traffic/parking modelling component. This forced the organisational team to create the block structure, and reserve the interdisciplinary interaction components to a final capstone project. Block 2 for instance now addresses the requirements of the mathematicians. Further interaction is no longer present until the final project. Hence the module structure forced the organising teacher team to constrain their goals for the project. As one organiser put it, the project is more like a complex case study. A more open project with real problem owners from outside would introduce more challenges in terms of creativity and would allow for more diversity in solutions. However in his view given the constraints this is a workable solution in which students from different disciplines can show their gained skills during the project.

As such the module organisation and the project itself represent an accommodation of particular institutional constraints stemming from disciplinary educational requirements and their relative inflexibility. This of course restricts somewhat the lessons this module might have for other programmes to those that match its own circumstances and combination of disciplines. However the lessons are general insofar as specific institutional demands are likely to be encountered whenever interdisciplinary modules are asked to provide both disciplinary and interdisciplinary education (Hasna 2010; McNair et al. 2011). In this respect this module represents one strategy or model for handling these constraints. Insofar as the project itself is considered a test of disciplinary skills and knowledge for each participating group, these constraints served to shape the project structure, and concerns like these are partially responsible for its modularity. As such this ID case study should be considered as an attempt to handle not only the cognitive constraints or challenges of doing ID work, but also the institutional challenges which derive from attempts to construct ID courses and curricula.

5. Closing remarks

In this paper we have argued for better scaffolding of interdisciplinary PjBL through better course and problem-design. Using a case of an interdisciplinary module, we have drawn attention to specific aspects of course design which might better afford genuine ID interactions between students. While we do not want to claim that open-structured problems might never be appropriate, we do want to promote reflection with respect to how interdisciplinary courses should be designed to facilitate meaningful interdisciplinary interactions (Hung 2011). At the same time what we advocate here does put more responsibility on educators, which raises important questions going forward now about how to structure the interactions between educators themselves in order to generate well calibrated interdisciplinary problem-solving tasks (Gast et al. 2018). Finally we think this case provides some empirical support to show that problem design can be an extremely important issue in the context of interdisciplinary project based learning, and can make a difference.

Note

1. ECTS = European Credit Transfer and Accumulation System, 1 ECTS = 28 h.

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