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The intended and unintended impacts on student ownership when realising CBL in mechanical engineering

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ABSTRACT

To increase students' sense of ownership, the present study incorporated elements of Challenge-based learning (CBL) into a mechanical engineering course. CBL is a desirable pedagogy adopted by many universities of technology. Although the boundaries and constraints of a regular course hinder the application of CBL, some of its benefits can be retained. In this paper, we investigate a second-year mechanical engineering course which aimed to give students autonomy in choosing their modelling projects, to facilitate students' ownership of their learning processes. The mixed-methods analysis of the intervention reveals no particular benefits of the intervention on pilot students' ownership, compared to a control group. The qualitative analysis suggests that implicit and explicit factors constrain ownership development, namely the anticipated difficulty level and official constraints for selecting projects. Our findings suggest that, currently, there could be too simple assumptions about how providing students with autonomy in selecting their projects allows for student ownership.

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Ownership; autonomy; modelling; mechanical engineering; challenge-based learning

1. Introduction

Students' ownership of their learning, that is, the extent to which they feel that what they are working on their own, has positive effects on students' academic performance as well as their well-being. In traditional teacher-centered teaching and learning models student ownership is limited. In active, student-centered learning environments, students are more in the lead of their own learning, with benefits including heightened motivation and academic performance (see Hernández-de-Menéndez et al. 2019). However, students can still remain rather inactive, taking on a consumer role rather than an active owner role. Counteracting such inactive roles, students need to be willing and able to make strategic decisions about their learning, e.g. in project-based formats (see Dounas-Frazer, Ríos, and Lewandowski 2019). To address this problem of lack of ownership, the current study aims to examine how ownership can be increased in the setting of engineering education. We contend that the implementation of Challenge Based Learning (CBL) approaches in many technical universities (e.g. 4TU.centre for Engineering education n.d.) offers huge potential for students to take ownership of their learning processes, because CBL emphasises learning through solving complex and urgent societal problems. Challenges are authentic and based on the real world, ideally in such a way that they relate to students' own daily lives (Gallagher and Savage 2020).

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In this paper, we investigate a second-year mechanical engineering course that aims to familiarise students with the discipline-specific practice of modelling, with a particular focus on facilitating students' ownership of their learning through the adoption of elements of CBL. The elements of CBL adopted in this course are, firstly, to give students freedom in choosing a modelling problem, and, secondly, to coach students to define their own learning goals with support from a tutor. We investigate the question:

> *To what extent does a CBL-inspired modelling learning activity in Mechanical Engineering, designed to realize student ownership for developing their discipline-specific knowledge base, lead to an increase in students taking ownership of their learning?*

We investigated this question in a mixed-methods intervention design with control group. In Section 2, we review literature on psychological ownership and modelling to substantiate the adopted elements of CBL for facilitating ownership. Section 3 presents the refined research question and hypotheses, after which Section 4 outlines the context and methodology of the study. Section 5 presents the results, showing that retaining the benefits of ownership of learning is more complex than current research suggests. Section 6 discusses this paper's findings.

2. Literature review

2.1. Ownership

Ownership is 'the state in which individuals feel as though the target of ownership or a piece of that target is "theirs" (i.e. "It is mine!")' (Pierce, Kostova, and Dirks 2003, 86). Ownership has three roots (Pierce, Kostova, and Dirks 2001, 2003; Breiting 2008):

1. *Self-efficacy*: Students feel that they have (some) control over their environment.
2. *Self-identity*: Students can express themselves through their work and/or can identify themselves with their work.
3. *Sense of belonging*: The individual feels 'at home' and has a place in the environment.

Students' ownership of their learning has many benefits, as it implies that students have control over their learning activities, that they are interested in the learning object, and that they are motivated (Pierce, Kostova, and Dirks 2001, 2003).

One's intrinsic motivation is essential for realising ownership. To address students' intrinsic motivation, the learning environment must at least meet the following three basic needs that motivate one to initiate activities and that are essential for psychological health and well-being (Ryan and Deci 2000):

1. *Competence*: This need refers to searching to control the outcome of learning and to experiencing mastery.
2. *Autonomy*: This need refers to the desire to be causal agent of one's own life and to act in harmony with your 'integrated self' (this is not the same as being independent of others).
3. *Relatedness*: This need refers to the will to interact with others, to being connected to others, and experiencing caring for others.

When these basic needs are fulfilled by the learning environment, students are assumed to feel a sense of ownership towards their learning and feel intrinsically motivated to direct their learning.

Research shows the benefits of both ownership and intrinsic motivation for students' academic performance as well as their overall well-being and satisfaction (e.g. Cordeiro et al. 2016; Sheldon and Filak 2008; Yu and Levesque-Bristol 2020). However, to the authors' knowledge, there is no research in engineering education which explicitly addresses the issue of systematically facilitating ownership, and available research on this issue is circumstantial. Factors that have been found in empirical research on facilitating ownership predominantly address the two roots *sense of belonging* and *self-efficacy*, in the widest sense. For instance, interactive learning (Lamont, Chaar, and Toms 2010) or giving student a say in assessment (Maskell 1999; Kolar and Sabatini 2000) could relate to sense of belonging and self-efficacy, respectively. Similarly, giving students control over content choices may benefit student ownership, as collaborative decision-making processes and having a say in learning content could allow students to own their learning (Missingham and Matthews 2014). Furthermore, making students responsible for producing relevant outcomes (Hadcraft 1997) could facilitate self-efficacy. Hence, together, these studies suggest that ownership often is a welcomed, but coincidental byproduct of student-centered learning environments in engineering.

2.2. Challenge-based learning and ownership

In an explicit effort to increase students' ownership, we look for inspiration from CBL:

> *Challenge-based learning takes places through the identification, analysis and design of a solution to a sociotechnical problem. The learning experience is typically multidisciplinary, involves different stakeholder perspectives, and aims to find a collaboratively developed solution, which is environmentally, socially, and economically sustainable. (Malmqvist, Rådberg, and Lundqvist 2015, 90)*

CBL emphasises that students take ownership of their learning, that is, students actively plan and direct their own learning processes (Gaskins et al. 2015). CBL poses that when students learn through solving such complex and pressing problems, this results in deep, meaningful, and purposeful learning activities in a hands-on and collaborative way (Nichols, Cator, and Torres 2016). Particularly, such learning activities result in students taking ownership of their learning (Gaskins et al. 2015), that is, students feel that they own the content of their learning.

The implementation of CBL requires widespread curricular changes on different scales, from the macro-level of university-wide changes to the meso- and micro-level of course-specific learning activities. For instance, to realise multidisciplinary learning in CBL, a wide range of changes on the macro- and micro-level are needed to experience interdisciplinary learning (Lattuca et al. 2017), such as teacher networks across disciplines and specifically designed learning activities (Van den Beemt et al. 2020). CBL as a concept can take on many forms, differing on dimensions such as open-endedness, degree to which issues are global, and the involvement of (external) stakeholders (Van den Beemt, van de Watering, and Bots 2021). Still, the relatively closed set of learning goals of a discipline-specific knowledge-building course does not seem to meet the brief for fitting under the term CBL. Nonetheless, it can be desirable to find those elements of CBL that can be realised for course-specific goals, within a course-specific curriculum and a course-specific schedule, while retaining specific elements so that the benefits of CBL for student ownership are maintained.

However, there is little research how to do so in such a way that it retains its benefits for student ownership. This gap is particularly relevant, even within CBL curricula, as developing students' knowledge base in first-year courses might best be developed in discipline-specific basic courses, where only specific elements of CBL are adopted in order for the course to develop discipline-specific practices in an accessible way.

2.3. Course design for ownership

To answer the research question of this paper, a Bachelor course on modelling of dynamic systems in Mechanical Engineering was redesigned such that it aligns with principles of facilitating student ownership of their learning. The curricular goal of the course is to develop students' discipline-specific knowledge base, that is, students' competences with the practice of modelling.

Modelling in engineering has the potential to realise student ownership, as modelling can engage students in authentic, motivating real-world problems which potentially relate to students' daily lives (cf. Section 2.1; Gallagher and Savage 2020). Modelling is an authentic element of engineering education, as modelling is a prominent part of engineers' professional practices in the work field (Lammi and Denson 2017; Carberry and McKenna 2014). As such, modelling problems potentially connect to students interests or their future work field. During modelling, students move through distinct stages (Maaß 2006) to translate a complex real-world situation into a (concise) mathematical model (Van Der Schaaf et al. 2006; Borromeo Ferri 2006). Particularly, mathematical modelling requires students to make decisions in the real world, in the stages of finding a real model and to interpret mathematical results with respect to what they say about the real-world problem (cf. Figure 1). Furthermore, translating real-world problems into the world of mathematics requires complex activities of visualising, simulating, algebraing or calculating, and interpreting and controlling thus obtained translations with respect to the original problem (Greefrath 2011; Borromeo Ferri 2006; Maaß 2006).

With respect to ownership, modelling in engineering has the potential to realise *self-efficacy*, *self-identity* and *sense of belonging* at the course level. Modelling provides learners with a structured set of activities suitable to tackle the increasingly pressing and complex engineering problems. With respect to self-efficacy, modelling could allow students to take control over their environment, for instance by giving students choice regarding modelling problems or by being responsible for producing meaningful outcomes (Czocher, Melhuish, and Kandasamy 2020). With respect to self-identity, modelling allows students to identify themselves with their work, as modelling is an authentic activity and addresses problems within their discipline of interest. With respect to sense of belonging, modelling engages students in collaborative activities in teams, where students can feel at home as apprentices of their discipline, while being coached and mentored by their teachers. As such, sense of belonging might also have an impact on deep learning (Diefes-Dux et al. 2012; Missingham and Matthews 2014). In sum, the intention of the course's redesign is to give students room to explore and follow their interest, make connections to their identity, and to recognise the relevance of the course contents for their future professional practice as engineer, in line with *self-efficacy*, *self-identity* and *sense of belonging*.

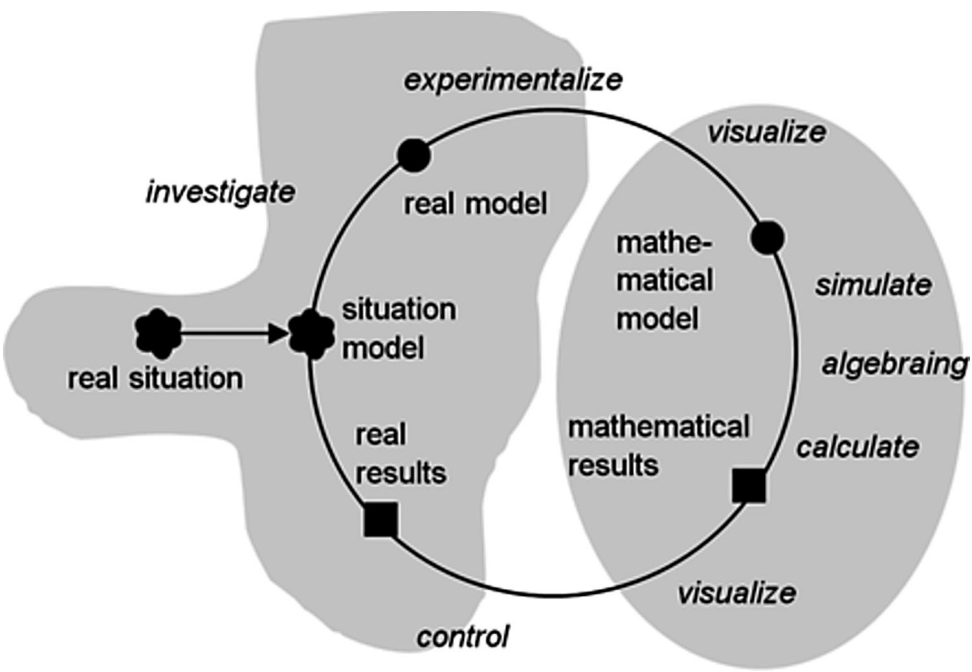

Figure 1. Modelling circle with its stages and activities (from Greefrath 2011, 303).

Three main modifications, inspired by CBL, were implemented in the course redesign, which have the potential to realise the above-described means to facilitate ownership:

1. *Self-identity:* Students can choose their own dynamic systems that they want to model, based on their own interests, under the condition that has an adequate level of difficulty (e.g. with respect to the number of free variables in the required model).
2. *Self-efficacy:* Students design their own experimental setup to investigate their chosen dynamic system. For instance, students have to decide how to collect data for validating their mathematical model.
3. *Sense-of-belonging:* The students are coached and scaffolded during their modelling process. For that, various tools are used, such as peer evaluation and peer feedback, as well as tools to manage the group progress, such as defining learning goals and distributing work packages.

The intention behind these modifications is to give students freedom to choose their own modelling problem within certain boundaries, such as to choose a modelling problem with no more than two free variables. Giving students choice potentially allows student to tackle authentic, motivating real-world problems that relate to students' own daily lives and are perceived as urgent.

3. Research questions and hypotheses

This paper investigates whether giving students choice of their modelling problem is successful in facilitating student ownership. For that, it employs a mixed method of rating the quality of ownership in videorecorded course sessions in a qualitative step and applying *t*-tests to compare students' discussions of ownership in pilot and control groups.

Research Question RQ1: Does the course redesign lead to a visible increase in student ownership?

RQ1 is addressed in a quantitative descriptive analysis, as outlined in the methodology section below.

Hypothesis H1

The course redesign leads to a measurable increase in pilot students' *self-efficacy*, *self-identity* and *sense of belonging*, when compared to control groups.

Hypothesis H2

The course redesign leads to a measurable increase in either pilot students' *self-efficacy*, *self-identity* or *sense of belonging*, when compared to control groups.

Hypothesis H3 (Null hypothesis)

The course redesign does not lead to a measurable increase in pilot students' ownership, that is, a measurable increase in pilot students' *self-efficacy*, *self-identity* or *sense of belonging*, when compared to control groups.

Research Question RQ2: In case of a confirmation of H2 or H3, what are possible reasons for students not developing either their *self-efficacy*, *self-identity* or *sense of belonging*?

RQ2 is investigated in a qualitative exploratory analysis, as outlined in the methodology below.

4. Methodology

4.1. Context, participants, and data collection

The setting of the research presented in this paper is a second-year mechanical engineering course on modelling dynamic systems at a Dutch technical university. The course typically has around 150 students and is organised around group projects. It takes place during one quartile (8 weeks) in the first semester of the academic year. For the purpose of the study, the course was evenly split into pilot groups and comparison groups, with each group consisting of 4–9 students. Table 1 provides an overview of the recruitment and data collection applied in the current study. The comparison

Table 1. Overview of recruitment of student groups and data collection.

Recruitment		Data collection						
				Week #				
Total student population	*Students opt-in for pilot*	*Condition*	*Group #*	2	3	4	5	6
150 students, in project groups of 4–9 students	→	Pilot	13	X				
			15		X			
			19		X			
			14			X		
			16				X	
			20					X
	→	Control	1	X				
			5	X				
			9		X			
			2			X		
			6				X	
			10					X

Note: 'X' marks the week in which the particular student group meeting was video-taped.

groups engaged in modelling pre-determined dynamic systems provided by the teacher, with a focus on hydrodynamics. Six control groups were followed to match the number of pilot groups. Next to the control groups, another eight groups engaged in the original course design, without being monitored in the current study. This setup has been the traditional design-based learning course design, so that the control group had the same quality of learning as in past instances of the course. The control groups followed an established schedule and established experimental setups, as in the previous years. In contrast, the pilot groups were required to choose a realistic situation with an underlying dynamic system that they want to model. Students chose for instance a figure skater doing a pirouette, a baseball bat hitting the ball, or a toy car speeding forward after being pulled back. The shared elements of these systems are that they contain movement induced by applied forces. After their choice of system to model, the pilot groups had to define their own learning goals and work packages, as described above. Students self-selected to be part of pilot groups.

The recruitment of the students follows convenience sampling, because participating students needed to volunteer for being part of the pilot group. This form of sampling ensures that pilot groups are willing to engage in educational innovation, and to accept organisational difficulties and inconsistencies about course goals and learning activities that result from participating in an educational innovation. Students were informed about the research through written informed consent. All necessary means were taken on the side of teachers and tutors to support pilot groups and to avoid organisational difficulties. Furthermore, tutors were familiarised with the ideas of ownership and trained to support pilot groups in finding a modelling project and in defining learning goals.

Data collection was designed to limit interference with the regular course activities. Accordingly, during the main five weeks of the student activity in the quartile (weeks 2 until 6), at least one pilot group and one control group tutoring session (60 min each) were videotaped per week (in weeks 2 and 3 three groups were videotaped). For instance, the pilot group 13 was videotaped in week 2, while the pilot group 20 was videotaped in week 6 (see Table 1 for an overview). While this setup does not provide longitudinal data from one group over the whole five weeks, it allowed to compare the general impact of the intervention on pilot students' activities with the control students' activities in the form of a weekly cross-section. Overall, twelve tutoring sessions from six pilot groups and six control groups were each videotaped during one 60 min. session, resulting in a total of 12 h = 720 min. of video data. Data collection followed the university's ethical standards of research with human participants.

4.2. Mixed-methods for data analysis

Ownership is conceptualised as a composite construct (cf. Section 2.1). In one dimension, the composite consists of the roots of ownership. As intrinsic motivation is a prerequisite for students to take ownership of their learning, the composite adds intrinsic motivation as additional dimension of ownership (Table 2).

In this paper, intrinsic motivation has been used to specify the particular learning activities in the redesigned course. Accordingly, when considering intrinsic motivation as a prerequisite of ownership, the elements of ownership can be conceptualised as specific, observable student proficiencies (cf. Table 2).

Using the composite construct of ownership, the video data of the tutoring sessions were analysed qualitatively in three consecutive steps. First, the categories of each table element (cf. Table 1) were specified, which included the identification of prototypical examples for each construct by the first and second author. Together with a research assistant, a shared understanding regarding the content of the main constructs was reached, resulting in operationalised analytical categories (cf. Table 3). Based on this understanding, the research assistant categorised all video material to identify episodes in which students negotiated their competence, autonomy, and/or relatedness, with a follow-up discussion in the team to arrive at consensual validity for categorising every episode. If no consensus could be reached, the episode was taken out of the dataset. If an episode fitted into multiple categories, this episode was included in the dataset for each construct.

Secondly, the selected episodes were transcribed verbatim. The length of the resulting episodes varied from 3 to 47 turns.

Thirdly, for each category, the first and second author and research assistant rated all episodes of that category with respect to the quality of how well this category is realised by students. For each category, three levels of quality were specified, from 1 (low levels of competence, autonomy or relatedness) to 3 (high levels of competence, autonomy or relatedness). For instance, the quality rating descriptions for the category of Autonomy 1 'autonomy in defining learning activities' (self-efficacy) were, ranging from low to high quality (the full set of quality rating indicators can be found in Table 4):

1. Students are autonomous to decide on learning activities, but ultimately make decisions based on task expectations (from teacher, from task).
2. Students have autonomy with respect to the decisions for their model, e.g. adding elements to their model/the measurements they do.
3. Students' autonomy in learning activities is rooted in their anticipation and planning as related to the entire project (how will the learning impact their future activities to reach an objective).

Table 2. Ingredients of student ownership, specified in line with students' basic need for intrinsic motivation (competence, autonomy, relatedness).

	Competence	Autonomy	Relatedness
Self efficacy Students feel that they have (some) control over their environment	Students are competent to define their learning goals and their learning development	To reach their goals, students autonomously define their learning activities	Students relate to each other through taking up specific roles
Self identity Students can express themselves through their work and/or can identify themselves with their work	Students are competent to evaluate the viability of project ideas, and choose one project	Students are autonomous in distributing and sharing work	Students relate to each other by seeing the added value of working in the group
Sense of belonging The individual feels 'at home' and has a place in the environment	Students are competent to accommodate for individual strengths and weaknesses	Students defend their autonomy towards teachers	Students relate to each other by feeling at home in the group

Table 3. Composite construct of ownership (left column), consisting of operationalised categories for self-efficacy, self-identity and sense of belonging (middle and right column).

Description (cf. Table 1)	Specified into category	Category description
Self-efficacy		
Students are competent to define their learning goals and their learning development	Competence 1	Students identify 1. gaps in their knowledge, 2. what they already know
	Competence 3	Students agree that learning goals have been reached
	Competence 4	Students evaluate their own learning outcomes (such as products, work packages, presentations)
To reach their goals, Students autonomously define their learning activities	Autonomy 1	Students define their own learning activities (to reach goals, cf. Competence 2)
Students relate to each other through taking up specific roles	Relatedness 3	Students agree on sharing a task.
Self-identity		
Students are competent to evaluate the viability of project ideas, and choose one project	Competence 2	Students define their learning goals.
	Competence 5	Students evaluate the viability of 1. modelling projects or 2. steps in the modelling cycle
Students are autonomous in distributing and sharing work	Autonomy 2	Students deal with frictions in the group (e.g. a group member's work is not sufficient)
	Autonomy 3	Students self-select for a task.
Students relate to each other by seeing the added value of working in the group	Relatedness 2	Students acknowledge the added value of each other's' different views and/or competences.
Sense of belonging		
Students are competent to accommodate for individual strengths and weaknesses	Competence 6	Students decide on the best person in the group to do a certain task, based on proficiency
Students defend their autonomy towards teachers	Autonomy 4	Students taking back autonomy from the tutor or teacher.
Students relate to each other by feeling at home in the group	Relatedness 1	Students acknowledge the added value of working in the group.

The quality ratings were consensually validated. For each episode, categories and quality ratings were checked and disagreements were discussed until a consensus was reached. In rare cases where no agreement was reached, the episode was excluded from the data, in all cases because the original categorisation was deemed inappropriate. This quality rating of learner activities with respect to ownership is an important qualitative outcome of this paper.

The categorisations and quality ratings resulted in two scores, that is, (a) a frequency count for how many episodes were found for each category and (b) a quality score for the average level that was reached in this category. The quantitative analysis consisted of independent samples *t*-tests to analyse the difference between control groups and pilot groups in terms of their ownership frequency and quality scores. One-sided testing was applied, because of the hypothesis that pilot

Table 4. Frequencies and quality scores for the composite constructs of ownership for the total sample, as well as the pilot and control groups separately.

	Total sample		Pilot		Control	
	M	*SD*	*M*	*SD*	*M*	*SD*
Self-efficacy						
Frequency	17.83	5.04	16.67	5.32	19.00	4.94
Quality	1.91	0.28	2.01	0.26	1.82	0.28
Self-identity						
Frequency	3.58	2.23	4.00	2.90	3.17	1.47
Quality	1.87	0.58	2.65	1.77	1.97	0.59
Sense of belonging						
Frequency	1.67	0.98	2.00	0.89	1.33	1.03
Quality	2.20	0.70	1.96	0.66	2.50	0.71

groups would have higher ownership scores than control groups, considering the nature of the intervention (see Hypotheses 1 and 2). While the significance of the quantitative findings is limited by the number of tutor groups of $N = 12$, the quantitative analysis can nevertheless reveal tentative results, particularly because of the powerful, ecologically valid video data of 720 min. duration used in the quantitative analysis. The results from the quantitative analysis were used to generate possible hypotheses about observed effects, by conducting a comparative analysis of the best-rated episodes for each category.

5. Results

5.1. Insights from quantitative analysis

Table 3 shows the ownership scores for the total of all 12 recorded sessions on the left side, and for the pilot and control groups separately on the right side. A repeated measures ANOVA indicated differences between the frequency with which the ownership categories were discussed, $F(1.33) = 105.65$, $p < .001$. Pairwise comparisons revealed more discussion of self-efficacy than of both self-identity ($p < .001$) and sense of belonging ($p < .001$). Moreover, self-identity was discussed with higher frequency than sense of belonging ($p = .017$). No differences were found across ownership categories in terms of quality, $F(2) = 1.84$, $p = .191$.

Contrary to our Hypotheses 1 and 2, independent samples *t*-tests revealed no differences between the pilot and control groups in any of the ownership categories. Pilot groups did not discuss any of the ownership categories with higher frequency than the control groups; self-efficacy: $t(10) = 0.79$, $p = .225$, self-identity: $t(10) = -0.63$, $p = .272$, and sense of belonging: $t(10) = -1.20$, $p = .130$. Also for the quality scores, pilot groups were not found to have higher scores than the control groups; self-efficacy: $t(10) = -1.17$, $p = .136$, self-identity: $t(10) = 0.57$, $p = .291$, and sense of belonging: $t(7) = -1.19$, $p = .138$. In other words, no indication was found that the null hypothesis (Hypothesis 3) should be rejected.

5.2. Insights from qualitative analysis

The quality rating indicators for the categories of the composite construct of ownership are a central result of this paper. Table 5 presents how we represented low, medium, and high quality in each of the categories identified in Table 3. As can be seen in Table 5, in groups with high ownership, students tend to acknowledge each other's contributions and competences and take a shared responsibility for the project, they give content and goal-oriented feedback, and are competent to make progress in the project. Furthermore, in these groups, students can frame their tasks so that they become interesting. Based on these high-quality ratings, it can be suspected that ownership might not be predominantly impacted by having a choice about a project, but by students' competences and their ability to 'craft' interesting and relevant tasks within a project.

Considering the results of the quantitative analysis, we conducted a further in-depth analysis of the data to investigate possible reasons for pilot- and control students' similar developments of ownership. In particular, we followed up on the category of *evaluating the viability of the project* (first category of self-identity), because we assume that the design of the course for giving pilot students choice over their modelling project should have the most impact in this category. In the following, we will illustrate how students develop ownership in the pilot and in the control groups. Particularly, we will show how the course setup gives students room to own their project. This way, we highlight that the simple notion of giving student choice is not a suitable variable to determine the degree of ownership that students are likely to develop.

The episodes below were chosen for their representativeness for a high quality of realising the category evaluating the viability of the project. Table 4 highlights the three levels of quality rating for the category 'Students evaluate the viability of 1. modelling projects or 2. steps in the modelling

Table 5. Quality indicators for the categories of ownership, as described in Table 3.

Self-efficacy				
Basic need (cf. Table 2)	Category (cf. Table 2)	Quality indicators		
		Low quality	*Medium quality*	*High quality*
Competence	Identify gaps in knowledge	Students declare they don't know something. The nature of the gap is unclear to students.	Students declare they don't know something. The students have a specific idea how to close gap.	Students declare they don't know something. One of the students has a concrete solution that immediately solves the problem.
	Reach learning goals	Students decide they reached a goal, but give no reasons or reasons not related to content.	Not found.	Students have several reasons for deciding that a learning goal has been reached.
	Evaluate learning outcomes	Students' perceived competence is not increasing – or even decreasing through negative personal feedback (not creative, talking too fast)	Students' perceived competence remains neutral (e.g. you did a good thing, but we need something else)	Students perceived competence is raised through positive, content- or goal-focused feedback
Autonomy	Define learning activities	Students are autonomous to decide on learning activities, but ultimately make decisions based on task expectations (from teacher, from task)	Students have autonomy with respect to adding elements to their model / the measurements they do / the decisions for their model.	Students' autonomy in learning activities is rooted in their anticipation and planning (how will the learning impact future activities to reach an objective)
Relatedness	Share a task	Collaboration / sharing is a byproduct of distributing tasks in the group or of a need for workforce.	Collaboration / sharing is a result of accommodating an individual's preferences/ competences (e.g. switching students because one student does not feel comfortable with a task)	Collaboration / sharing is done as a means to exploit the groups competences in the best possible way, to achieve the task in the best way.
Self-identity				
Basic need (cf. Table 2)	Category (cf. Table 2)	Quality indicators		
		Low quality	*Medium quality*	*High quality*
Competence	Evaluate modelling	Students see no way to do project, because they lack the competence to have ideas for how to proceed or tackle the problem.	Students are not sure whether they are competent enough, but they have ideas about how to address the challenge and to develop their competence.	Students agree that they have the necessary competence to proceed with the project, and the ideas put forward are regarded as viable by the group.
Autonomy	Self-select for a task.	Students' self-selection contributes to the larger goal, so the student self-selects for the benefit of the group (reducing personal autonomy, but maintaining autonomy of group)	Students have the autonomy that while taking up required task, they can adapt the task to better suit their interests. (task is made interesting) or they can choose the task that fits best.	Students have the autonomy to follow their interests in doing the project tasks (task is interesting)
Relatedness	Added value of each other's' different views and/or competences.	Students work together because combined workforce is needed (division of labour)	Students work together because it combines multiple competences / multiple opinions	Students work together because they acknowledge a shared responsibility to produce something (i.e. talk about 'we' instead of each having ones share and doing an individual part)

(*Continued*)

Table 5. Continued.

Self-efficacy				
Basic need (cf. Table 2)	Category (cf. Table 2)	Quality indicators		
		Low quality	*Medium quality*	*High quality*
Sense of belonging				
Basic need (cf. Table 2)	Category (cf. Table 2)	Quality indicators		
		Low quality	*Medium quality*	*High quality*
Autonomy	Take back autonomy from the tutor	Tutor/teacher provides next steps; students follow	Tutor/teacher gives input; students take it into account in making their own plans	Tutor/teacher provides hint/ input; students are in charge of whether or not & how they are taking it into account
Relatedness	Added value of working in the group	Students work together because combined workforce is needed (division of labour)	Students work together because it combines multiple competences / multiple opinions	Students work together because they acknowledge a shared responsibility to produce something (i.e. talk about 'we' instead of each having ones share and doing an individual part)

Note: Categories with too few episodes (defining learning goals; dealing with frictions; dividing tasks based on proficiency) were omitted from the table.

cycle'. The episodes take place in the second week of the course, where students must decide which project to pursue in the upcoming weeks.

5.2.1. How students evaluate the viability of the project they are pursuing in the control group (W2C1 Week 2 control 1)

In the control group, students are given a specific project. As student groups in the control condition are assigned specific dynamic systems, they do not directly need to evaluate the viability of the project itself. However, students typically discuss the viability of specific approaches to their project. For instance, students can discuss the viability of different approaches for measuring a specific phenomenon.

The following episode from week 2 of the course illustrates how students gain self-identity. It belongs to the category Competence 5, as the students (Group 1) try to decide on a specific method for measuring water levels in a dynamic system with changing water levels. Note that students discuss their measurement plan (Turns 1–2), finding that measuring with a laser is not a viable option (T3–5). Then, the students come up with alternatives (T6–8).

Time	Turn	Student	Verbal utterances and, if needed, description of gestures in [brackets]
21:25	1	Sophie	The measurement plan was yours right *[points at Levi]*
	2	Levi	Yeah it was mine, yeah well.. some things are important to know in this project like the velocity of the pump the flowrate and the velocity of the change of the water level. The change of the water level is by hand I think hard to measure because you don't know yeah what changes in height and time you exactly get some person on canvas asked in discussion how you can more accurate measure this and the answer of [the teacher] was to do it with a laser but there are no equipment available so I thought maybe we could discuss if we wanted to do it with a laser or by hand to yeah in order to measure this as accurate as possible
	3	Ton	Do you have a laser from your job? *[some students laugh]*
	4	Stephan	So the laser is probably not going to work it's really nice that they suggest this but yeah.. we don't have a laser so that was [bad] advice
	5	Mike	I also may have a laser, but I don't know how to operate it..
	6	Stephan	Ok, maybe we can try and find out if we can.. get one because they do suggest it so.. another idea that I have is you can simply put something in the water that floats just like this *[shows with hands]* and if

(*Continued*)

Continued.

Time	Turn	Student	Verbal utterances and, if needed, description of gestures in [brackets]
			you make a video out of it you can do motiontracking in MATLAB. I've never done this don't know how it works but I know it's possible
	7	Lucas	# Is it hard?
	8	Mike	# Is it possible?
23:10	9	Stephan	Yeah, you can make a video and then.. because there's noise on it due to the waves you can also get like a moving average so.. you can plot a line through it or something like that. Ehm this is maybe something to look into for the next SSA for like how can we measure the water level

This episode highlights how students exercise control over their project. Most prominently, the students evaluate a teacher's advice to use a laser to measure the change of water level in their dynamic system. This advice was given to the whole course via a discussion on the learning platform Canvas (T2). However, as there is no laser available and students declare they are not proficient in using a laser (T3, T5), the students regard this as '[bad] advice', although it may also reveal an underlying issue with their planning skills. Instead, a student proposes an alternative way to tackle the issue, namely, to use a floating ball and motion tracking in MATLAB (T6, T8). Accordingly, the group has two options in their real model (cf. Figure 1) for how to approach a specific issue in their project, which may have an impact on the mathematical model and its viability. In other words, the students take control over their project with respect to how to approach measuring water levels, even to the point where they disregard the teacher's advice.

With respect to ownership of their learning, this episode highlights students' self-identity. Particularly, the students form their self-identity through pragmatically uniting against the teacher's advice. Notably, students' competence is crucial for uniting against the teacher, particularly Stephan in Turns 6 and 9 can give a rather elaborate alternative plan for measuring water levels, based on his knowledge of MATLAB and his mathematical creativity in proposing calculating average water levels from their measurements. His utterances suggest that Stephan anticipates issues in the real model and can mentally project how to compensate for this in the mathematical model.

With respect to students' autonomy, the students reclaim autonomy from the teacher, by critically evaluating and disregarding the teacher's advice (T3–T6). Also, being able to come up with an alternative idea lets the group feel competent, and helps the group make progress independently from the teacher (T6).

In summary, this episode shows students ownership, firstly in taking control of the measurement issue and secondly by becoming autonomous as group. Accordingly, the students own their learning, as they feel that their choices have been their own choices.

5.2.2. How students evaluate the viability of the project they are pursuing in the pilot group (W2P13 Week 2 pilot 13)

In the pilot group, students can choose a project, with the course providing examples of projects and specifying the number of free variables that the project should model. Typically, the pilot groups come up with different project ideas and then select a particular project. The students are asked to document their decisions, so they need to give a good rationale why a specific dynamic system was selected in their modelling activity, and why other dynamic systems were disregarded.

The following episode from week 2 of the course illustrates how students gain self-identity. It belongs to the category Competence 5, as pilot students (Group 13) try to decide on a specific modelling project, in this case between two options of modelling an arrow being shot or a toycar. Note that students discuss the connection between difficulty and detail level (T4–5) and compare the number of variables that need to be modelled (T5–T12). Finally, the students consider course recommendations (T13–20) to arrive at a decision.

Time	Turn	Student	Verbal utterances and, if needed, description of gestures in [brackets]
26:35	1	Rob	What do you guys think will be more.. challenging? Because I'm not sure
	2	Chris	I have no idea
	3	Rob	What would be the more difficult thing to do?
	4	Chris	I think it's dependent on how far you are willing to go into the details
	5	Rob	Yeah how far can you go into detail with the toy car.. I mean for example friction of the toy car on the wheels.. you can make it as difficult as you want.. but the whole system of it.. just a spring some gears and run.. well in the bow with the trajectory arrow and air I think you can go pretty far
	6	Chris	If we do ehm ehm calculate the trajectory of the arrow and we don't have a single degree of freedom anymore.. because the trajectory is at degree two
	7	Rob	Ehm the angle of ehm the bow.. the placement of the bow..
27:37	8	Chris	If we go for two dimensions then it's two degrees of freedom if we go for three dimensions I think.. yeah that would be three at least if we don't ehm think about rotation …
	9	Rob	Why wouldn't we think about rotation?
	10	Chris	Well.. in 3D that would be six degrees of freedom [5sec]
	11	Tim	What did you want to say *[looks at #2]*
	12	Josh	I was thinking if we do it in 2D which I think is much better … yeah.. if you know the angle at which the arrow starts I think you can predict the ehm trajectory
	13	Chris	I'm not saying it's impossible but it's not one degree of freedom anymore …
	14	Tim	Yeah it was in the ehm
	15	Chris	It was recommended to do one degree of freedom
29:32	16	Bart	Best is if there is one degree of freedom
	17	Tim	Yeah that's the only one that's different for the bow and the toy car …
	18	Stan	That's maybe why we should go for the toy car [5sec]
	19	Rob	Is there anyone disagreeing with going for the toy car? [5sec]
	20	Tim	No then the toy car it is

The episode illustrates how students decide on a project, particularly the factors they consider for arriving at a decision. In the beginning, the students' try to determine the difficulty levels of their two options (T1, T4-5). Later, they evaluate their two options with respect to the degrees of freedom in each modelling project (T13–T17), having in mind the course recommendation for aiming for one degree of freedom (T15). These segments show that students take control over the depth of their modelling activities, by anticipating possible elements of the model (e.g. T5). At the same time, course constraints directly and indirectly influence the students' choice: Directly, because the course recommendation of choosing a dynamic system with one free variable is impacting students' choice of their modelling project. Indirectly, because choosing a less difficult project will ensure that students will be able to fulfil the course demand of modelling a dynamic system. The course teachers did indicate that if students would take more risk, this could lead to a less suitable model, but that this would not affect their grade. However, students did not seem willing to take that risk.

With respect to the ownership of their learning, the episode shows pilot students self-identity in choosing a modelling project, suggesting that expressing themselves is not a priority for these students. Self-identity describes how students express themselves through their work and/or how they identify themselves with their work (cf. Table 1). While the students seem to find both modelling projects suitable for the course, the above-highlighted direct and indirect course constraints guide students to make a choice. These constraints seem to have more weight than the interestingness of the modelling problems, as the following exchange at an earlier point illustrates:

Time	Turn	Student	Verbal utterances and, if needed, description of gestures in [brackets]
Min 24.30	5	Chris	No it happens because the arrow is compressed by the spring and then it bends and then it starts oscillating [5sec]
	6	Rob	Well we can try.. we have ehm six people and one month the time … if it doesn't work then it doesn't work

In this earlier episode, Chris seems to be particularly knowledgeable about the arrow problem, suggesting some interest in this problem. In response to Chris, Rob suggests following up on the arrow problem, despite course constraints, pointing to the groups combined workforce and the possibility that real-world projects can fail. Together, although Rob seems willing to take the risk, it seems that for his group members the course constraints take prevalence over opportunities for expressing themselves through their modelling projects.

Notably, these episodes further highlight a close connection between students' competence and their self-identity. As Turn 5 (Episode 1) and Turn 5 (Episode 2) highlight, the students' knowledge about the situation model and real model (cf. Figure 1) is crucial for discussing the projects' viability for the course. Particularly, the students' anticipation of the elements of the real model informs is a precondition for students to evaluate the modelling projects viability when considering direct and indirect course constraints.

5.2.3. Comparative perspective on students' ownership

The two episodes highlight that students' ownership of their learning of modelling dynamic systems faces opportunities and constraints. For instance, students can experience self-identity in the control group, as the modelling circle gives room for students to 'control their environment', in this case, to make decisions about how to conduct measurements. On the other hand, in the pilot group, where students were intended to have more control over their modelling project, students' reasoning is limited by implicit and explicit organisational constraints of the course, such as difficulty level and recommended degrees of freedom in the project. Furthermore, with respect to self-identity and sense of belonging, the pilot condition of giving students choice seem to be insufficiently realised, as implicit and explicit organisational constraints might have a higher impact on students' decisions than their interest in choosing a modelling project. In fact, in the pilot group episodes there is little evidence which suggests that students follow their interest or that they consider the relevance or urgency of problems while identifying possible projects to pursue. Thus, with respect to realising features of CBL on the course level, giving students' choice for their modelling projects is not a sufficient means to facilitate ownership, but seemingly requires further course changes that can address the above-described implicit and explicit constraints.

The episodes presented here suggest a further important factor in students' ownership of their learning, namely a level of competence that allows the group to gain an overview over the real model and to predict the impact of certain decisions on the mathematical model (Figure 1). When it comes to their feeling of competence, which Ryan and Deci (2000) describe as searching to control the outcome of learning and to experiencing mastery, it is evident that the students' control of their learning environment is determined by their competence to predict the variables of the model of the situation at the beginning of the project. As a result, students' ownership of their learning could potentially develop equally well in both the pilot and the control groups, depending on the students' previous knowledge they bring to the project. In other words, students' competence of anticipating possible solutions of an interesting and relevant problem could be a prerequisite for choosing this problem as a modelling project, and hence this competence could be a prerequisite for developing ownership as intended.

6. Discussion

This paper reports findings from a course redesign in Mechanical Engineering which aimed to increase students' ownership, inspired by elements of CBL. The intention of the course redesign was to retain CBL's benefits on student ownership by giving students freedom to choose their own modelling projects. To investigate the benefits of this redesign, an intervention study with control group was designed, with video recordings of tutorials as data. Based on a qualitative categorisation of the video data with respect to student ownership (Table 3) and a subsequent quality rating of student ownership (Table 5), we conducted independent samples *t*-tests to compare student ownership in the pilot and control groups. Contrary to our hypotheses and contrary to the expectations in the course redesign, we found no evidence that the pilot intervention leads to a higher frequency of episodes where students show ownership of their learning or to a higher quality of their discussion of ownership. A follow-up in-depth analysis of specifically selected episodes highlights that implicit and explicit course constraints including students' risk-taking versus risk-avoidant behavior as well as students' competences could have a higher impact on student ownership than anticipated in the course redesign. Particularly, implicitly, the anticipated difficulty level of projects, and, explicitly, the course recommendations for modelling projects constrain students' ownership of their learning, while students' competence to anticipate the real- and mathematical-model seem to positively impact students' ownership in both, the pilot and the control groups.

Our findings suggest that, with respect to ownership, retaining the benefits of CBL on the course level could be more complex than research on ownership in engineering education currently suggests. In particular, we find that on the level of student interaction, ownership is constrained or enabled by a complex amalgam of factors (cf. Table 5), including factors not anticipated or accounted for in the course redesign. Accordingly, this paper's finding of a complex amalgam of factors that impact student ownership is in contrast to previous research in engineering education which assumes a simple causality between giving student more say in their learning and student ownership (e.g. Kolar and Sabatini 2000; Lamont, Chaar, and Toms 2010; Maskell 1999). Hence, the assumption that giving students autonomy to choose their project in general facilitates student ownership (e.g. Gaskins et al. 2015) needs to be further investigated.

Based on this paper's findings, it can be suspected that students' available competences and their knowledge base for engaging in collaborative learning and modelling activities could play a major role for students to be able to take ownership of their learning, as is the case here for students' competence to anticipate models. Similar to Ryan and Deci (2000) who find competence to be a relevant factor for students to develop intrinsic motivation, this paper finds evidence that competence might be a relevant factor for students to develop ownership, as it has a crucial impact on students' realisation of specific modelling steps (Figure 1). Possibly, students' competences point to the didactical paradox (Brousseau 2006) of ownership: If teachers set boundaries and suggest knowledge for tackling a challenge, students cannot fully own their learning. However, if the teacher refrains from setting these boundaries and from pointing to relevant knowledge, the student is treated as if he/she already has the knowledge he/she is supposed to learn (Radford 2012). Hence, designing learning activities not only need to account for students' available competences, but they need to account for how students can gain ownership. In other words, how can learning experiences be designed in such a way that the boundaries of these learning activities do not inform students reasoning, and, this way, limit their ownership of their learning?

The quantitative analysis has not revealed a benefit of the intervention on students' ownership of their learning. Most likely, this non-result of the quantitative analysis can be explained by the small number of groups with $N = 12$, and the small number of pilot groups ($n = 6$), resulting in limited power to detect differences that may actually have been present (see Cohen, Manion, and Morrison 2018). Nevertheless, the quantitative data is backed by a large dataset, so that the non-result allows for an interpretation of the difficulty of facilitating ownership. Possibly, the qualitative data analysis that prepares the quantitative data could be biased towards a positive sampling of those episodes where student ownership is particularly evident, while more sublime developments over longer time periods might not have been captured in the episodes selected. Similarly, as there is no video data on the students' project work outside of the tutorials, some relevant developments of students' ownership might not have been captured. It might well be that students developed ownership during the practical work of their projects, and tutor interviews suggest that this might have been the case for some groups. Furthermore, the non-result might be explained by the bandwidth-fidelity dilemma (Cronbach and Gleser 1957): The here-used construct of ownership (cf. Table 1) might be too multifaceted, that is, might have a too high bandwidth, to capture the specific developments of ownership triggered by the here-investigated intervention. It might be that the here-investigated intervention only affected students' self-identity in meaningful ways, as visible in Section 4.2, but not the other elements of student ownership, which would have required a more fine-grained categorisation of self-identity within the construct of ownership than the one developed in this paper. Finally, it might be the case that the original course design already contained elements that supported students' development of self-efficacy, self-identity, and sense of belonging. That is, students already worked in small groups on their problems, with some say about the learning trajectory they took. We indeed found multiple ownership-related episodes in the control groups as well. To further increase students' ownership in a course redesign requires a broader range of changes to support ownership, with giving students choice of their project being a necessary, but not sufficient change.

Future research needs to address how to facilitate students' ownership of their learning, particularly considering the here-found factors that could possibly impact learning in CBL-contexts in general, and student ownership in particular. For instance, how can CBL be implemented in an institutionalised setting of universities, while avoiding students 'playing it safe' by aiming for fulfilling course criteria and by working within the boundaries of course requirements for successfully finishing a course? Furthermore, with respect to the didactical paradox mentioned above, the role of teachers and tutors as coaches of learning processes needs to be investigated. Particularly, how can tutors and teachers coach students in such a way that students follow intended learning pathways, without giving away the learning content?

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