Research Proposal Innovation Fund

Project Title:

Deepening Multidisciplinarity within Systems & Control

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List of Abbreviations

CBL	Challenge Based Learning
TU/e	Eindhoven University of Technology
AP	Applied Physics
ME	Mechanical Engineering

1.Introduction

1.1. Project Information

At Eindhoven University of Technology (TU/e), the collaborative project of the departments Applied Physics (AP) and Mechanical Engineering (ME) entitled: "3BYX0P – Challenge Based Learning (CBL) Systems and Control project" was granted. This project is initiated in December 2020 and the expected closing date is December 2021. The project includes planning and management, literature review, data collection and analysis in the context of the course; 3BYX0P-CBL Systems and Control, data analysis and dissemination of the findings. The total project budget is 11.650 Euros. This project is an accompanying research linked to another TU/e project; CBL - Systems and Control. Our project focuses on the multidisciplinary aspect of the course.

1.2. Background to the Project

Current educational practices put great emphasis on equipping students with higher-order thinking skills, competencies such as creativity and communication, and an awareness of societal problems (Elliott, Oty, McArthur, & Clark, 2001; Ghanizadeh, 2017; Organisation for Economic Co-operation and Development [OECD], 2018). Interdisciplinary learning environments have the potential to develop these qualities and contribute to student learning (e.g., Ivanitskaya, Clark, Montgomery, & Primeau, 2002; Knobloch, Charoenmuang, Cooperstone, & Patil, 2020; Lattuca, Knight, Seifert, Reason, & Liu, 2017). Some of the rationales for bringing interdisciplinary learning environments to the forefront include preparing students to discuss global problems and raising students as life-long learners and problem solvers (Boix-Mansilla, 2010). Interdisciplinary courses help students appreciate multiple disciplinary perspectives through informed collaborations (Knobloch et al., 2020).

For a learning environment to be classified as interdisciplinary, the scientific disciplines (e.g., physics, computer engineering, chemistry, psychology, management) should be integrated in meaningful tasks and the disciplines should not be left disconnected throughout these given tasks (Drake & Reid, 2018; Gentili, 2019; Gresnigt, Taconis, van Keulen, Gravemeijer, & Baartman, 2014). Engineering education is expected to (National Academy of Engineering, 2004): "…embrace the potentialities offered by creativity, invention, and cross-disciplinary fertilization to create and accommodate new fields of endeavor, including those that require openness to interdisciplinary efforts" (p. 50). Interdisciplinary engineering education aims to equip students with the abilities to meaningfully bring together the content and methods of different disciplines in a certain context (Van den Beemt et al., 2020). At the core of interdisciplinary learning environments is the integration of knowledge from multiple disciplines around an overarching theme or a problem essential for student learning (Holley, 2017; Klaassen, 2018).

TU/e describes the engineer of the future as an individual who can function effectively in interdisciplinary settings (TU/e Strategy 2030, 2018). The vision statement highlights (TU/e Strategy 2030, 2018).: "…a new type of public-private partnership where interdisciplinary teams of people from multiple organizations work together in specific projects to bridge the gap between scientific findings and commercial development" (p. 4). Challenge based learning (CBL) has merit in accomplishing these goals as it draws on the knowledge of multiple disciplines in providing solutions to real-world problems (Gonzalez-Hernandez, Cantu-Gonzalez, Mora-Salinas, & Reyes-Avendaño, 2020). CBL contributes to maintaining the rigor of different disciplines while presenting a truly authentic problem/challenge that establishes links between the disciplines. CBL calls for a more integrated or holistic approach as well as meaningful learning experiences (Gallagher & Savage, 2020).

The CBL course; 3BYX0P – CBL Systems and Control integrates the knowledge and methods of the two disciplines; AP and ME around a specified challenge. The course includes 30 registered students in total registered from two departments: seven AP students and 23 ME students. The students are collaborating in multidisciplinary teams of six throughout the course. This project focuses on the multidisciplinary teamwork aspect of this course. Multidisciplinary teamwork is of great value in that it allows for the interaction and collaboration of students coming from different disciplines. The findings of this project can be inspirational for: a) the improvement of the course; 3BYX0P– CBL Systems and Control and b) the development of similar courses at TU/e.

2.Conceptual Framework

2.1. Interdisciplinary Higher Engineering Education

There is an ongoing shift towards interdisciplinary approaches in higher education. TU/e's 2030 vision statement also highlights the importance of raising tomorrow's engineers and scientists with an interdisciplinary mindset (TU/e Strategy 2030, 2018): "The world of research has changed, from monodisciplinary, individual pursuits to a reality in which researchers rely on personal grants to conduct curiosity-driven, interdisciplinary research. Nowadays, public-private consortia cooperate in large international research programs" (p. 16). One reason for this transition lies in the critique towards exposing students only to contexts of specialized disciplinary knowledge (Holley, 2009). Universities are challenged to bring together the content and methods of different disciplines which might mean collaboration of different campus departments or external collaborations with industry partners (The National Academies of Sciences, Engineering, and Medicine, 2021). The general vision for interdisciplinary engineering education includes solving societal problems, developing engineering students as individuals who are aware of the connection between real-world issues and interdisciplinary approaches (Van den Beemt et al., 2020).

There are different approaches to curriculum integration ranging from fragmented to trans-disciplinary (Gresnigt et al., 2014). Interdisciplinarity is one of the curriculum integration approaches within the scope of this range (Gresnigt et al., 2014). Two of the important features of an interdisciplinary course design can be outlined as: a) defining the learning outcomes without necessarily referencing to individual disciplines and b) using problems or projects as a core anchor during the course (Gresnigt et al., 2014; Smith & Karr-Kidwell, 2000). In interdisciplinary courses, knowledge and methods of different disciplines are integrated under a certain problem or a theme (Holley, 2017). In a CBL course environment, students work on real-world challenges as they gain or deepen knowledge and skills (Gallagher and Savage, 2020). Through CBL, students engage in real-world problems (TU/e Strategy 2030, 2018): "…challenge-based learning is a broader concept, involving team work, interdisciplinarity and a systems-level approach" (p. 30). With CBL courses, interdisciplinary real-world challenges such as soil quality improvement, food safety and sustainability (United Nations Environment Programme, 2012) are introduced. CBL puts a clear focus on local or global real-life challenges and facilitates students' identification and definition of specific problems related to those challenges (Pepin & Kock, 2021).

In their recent systematic literature review, Gallagher and Savage (2020) revealed the prominent features of CBL. The results show that one of the features is multidisciplinarity that advocates collaboration of multiple disciplines as the students work on challenges together.

2.2.Multidisciplinary Teamwork

There are different terminologies used interchangeably to describe the teamwork of students coming from multiple disciplinary backgrounds such as diverse teams (Hayes & Kejnar, 2020), interdisciplinary teams (Murphy et al., 2015), cross-disciplinary teams (Yazici, Zidek, & Hill, 2020), and project-based teams (Schaffer, Chen, Zhu, & Oakes, 2012). This project adopted *multidisciplinary teamwork* to define AP and ME students' multidisciplinary interactions and learning in teams. The team members extend their disciplinary knowledge towards a more holistic understanding in a multidisciplinary team context (Butler et al., 2019).

The team members are expected to: a) identify their own skills and knowledge and their own contributions to the project, b) interact with the team members to clarify their disciplinary contributions to the project, and c) appreciate and synthesize other disciplines' knowledge in relation to the project outputs (Schaffer et al., 2012). It is important to have students work collaboratively on problems, specifically, to equip students with the competencies to function successfully in multidisciplinary teams (Lattuca, Knight, Ro, & Novoselich, 2017). Multidisciplinary teamwork is evidenced to have positive impacts on students' skills development and learning of course content (e.g., Bekke & Mersha, 2018; Sharma, Steward, Ong, & Miguez, 2015; Spelt, Luning, van Boekel, & Mulder, 2017; Weinberg, White, Karacal, Engel, & Hu, 2005; Yazici et al., 2020). Students report that such collaborative projects enhance their vision in understanding how people from other disciplines think and also in appreciating multiple disciplinary perspectives' contributions to mutual team goals (Waryoba, Demi, & Fatula, 2016).

In today's world, the demand for graduates who are capable in working in multidisciplinary teams is growing (DePiero & Slivovsky, 2017; Sharma et al., 2015). Creating value in society is partly connected to skills to function in collaboration with others (OECD, 2018): "…innovation springs not from individuals thinking and working alone, but through cooperation and collaboration with others to draw on existing knowledge to create new knowledge. The constructs that underpin the competency include adaptability, creativity, curiosity and open-mindedness" (p. 5). This project aims to investigate the potential changes in students' competencies to work in multidisciplinary teams and how multidisciplinary teamwork contributes to learning from a comprehensive perspective using multiple data sources.

In order to enhance the functioning of multidisciplinary teams, it is useful to have an understanding of the potential facilitators of multidisciplinary teamwork. The functioning of multidisciplinary teams is primarily effected by the following factors; the learning environment; the course curriculum, the problem or the challenge that the team is working on, course content and tasks, teacher behavior and guidance, team elements such as members; commitment, communication and organization, and individual factors such as personal characteristics and prior experiences (Almajed, Skinner, Peterson, & Winning, 2016; Butler et al., 2019; Richter & Paretti, 2009; Spelt, Biemans, Tobi, Luning, & Mulder; 2009; Spelt, Luning, van Boekel, & Mulder, 2015). Investigating these potentially enabling conditions at a unique course setting at TU/e can foster our understanding on how to further facilitate multidisciplinary teamwork and therefore how to contribute to students' capacities to work in these teams.

2.3. Significance of the Project

The integration of multiple science and engineering disciplines to solve real-world challenges offers opportunities for positive student outcomes (e.g., Holzer et al., 2018; Knobloch et al., 2020; Lattuca et al., 2017). This project presents a CBL course context that addressed the link between a real-world challenge and the content and methods of the disciplines; AP and ME (Drake & Reid, 2018).

Working in multidisciplinary teams to create design solutions is one of the core features of CBL (Gallagher & Savage, 2020; Malmqvist, Radberg, & Lundqvist, 2015). Because higher education curricula mostly have a detached structure of disciplines (Holley, 2017), the project can contribute to the shift towards more interdisciplinary structures which in return can improve students' functioning in multidisciplinary teams. Multidisciplinary teamwork in a CBL context can facilitate students' understanding of the links between multiple disciplinary knowledge and creating a useful design solution (Gallagher & Savage, 2020; You, 2017). One challenge is concerned with discussing aspects of assessment of student learning and improvement in relation to interdisciplinary engineering education contexts. The comprehensive review by Van den Beemt et al. (2020) demonstrated that assessment in interdisciplinary higher engineering education is not fully discussed yet and that more research needs to be conducted. If students' learning and improvement in interdisciplinary learning environments are not well-defined and assessed, educators might provide courses falling short on giving some essential feedback. This project will explore multidisciplinary teamwork focusing on both: a) students' learning of the course content and b) students' competencies to work in the multidisciplinary teams. Relying on multiple perspectives (students and teachers) and including well-aligned data collection sources (survey, interview, observations) can reveal an in-depth understanding of a CBL course context from a multidisciplinary teamwork perspective.

Despite ongoing delivery of CBL courses, there is yet no research conducted with regards to the multidisciplinary teamwork aspect of a CBL learning environment at TU/e. Guided by this fact, the current study aims to explore multidisciplinary teamwork in the setting of the course; 3BYX0P-Systems and Control and to understand how multidisciplinary teamwork affect student learning and improvement. The project *presents novelty because:* a) results can contribute to the recently growing investigations of learning in CBL environments, b) the research will touch upon the need to comprehensively assess student learning and improvement with regards to multidisciplinary teamwork using multiple data collection strategies, c) findings will be inspirational in exploring multidisciplinary team rather than the more common practice of measuring students' learning of disciplinary concepts and practices, and d) the results can guide future research on how to better promote multidisciplinary teamwork. The project outcomes (e.g., an adapted survey for use in interdisciplinary learning environments, implications for practice) will be shared for wider use.

2.4. Purpose of the Project

TU/e's 2030 strategy adopts the interaction between research and education as one of its pillars (TU/e Strategy 2030, 2018). Investigation of the unique multidisciplinary teamwork during a CBL course has the potential to create motivation for course designers in creating similar learning environments. Considering the existing views that describe multidisciplinary teamwork as challenging or not rewarding for improved learning outcomes, this project can facilitate transforming these views based on student outcomes and the value of multidisciplinary teamwork. The purpose of the project is two-fold: a) to investigate students' learning and improvement regarding the multidisciplinary aspect of the course; 3BYX0P – CBL Systems and Control and b) to explore the potential factors that foster multidisciplinary teamwork in the context of the course.

1. How does the multidisciplinary aspect of the 3BYX0P – CBL Systems and Control course affect students?

 1a. How does multidisciplinary teamwork impact students' learning of the course content?

 1b. How does students' competencies to work in multidisciplinary teams change during the course?

2.What are the elements of multidisciplinary teams that foster student learning?

3.Method

3.1. Research Design

The “Deepening Multidisciplinarity with Systems and Control” project is mainly designed as a mixed methods research. Table 1 presents the project alignment. In order to answer the first research question, the project adopted a convergent parallel design (Creswell, 2012) where elements of qualitative and quantitative research are combined in order to better understand the multidisciplinary aspect of the course; 3BYX0P- CBL Systems and Control with respect to student outcomes. In line with the convergent design, using qualitative and quantitative methods together is helpful for overcoming their individual weaknesses and for data triangulation purposes. This research design is useful when researchers combine a series of separate data collection procedures to inform each other (Creswell, 2012). The qualitative and the quantitative data will be collected and analyzed separately to arrive at complementary results (See Figure 1).

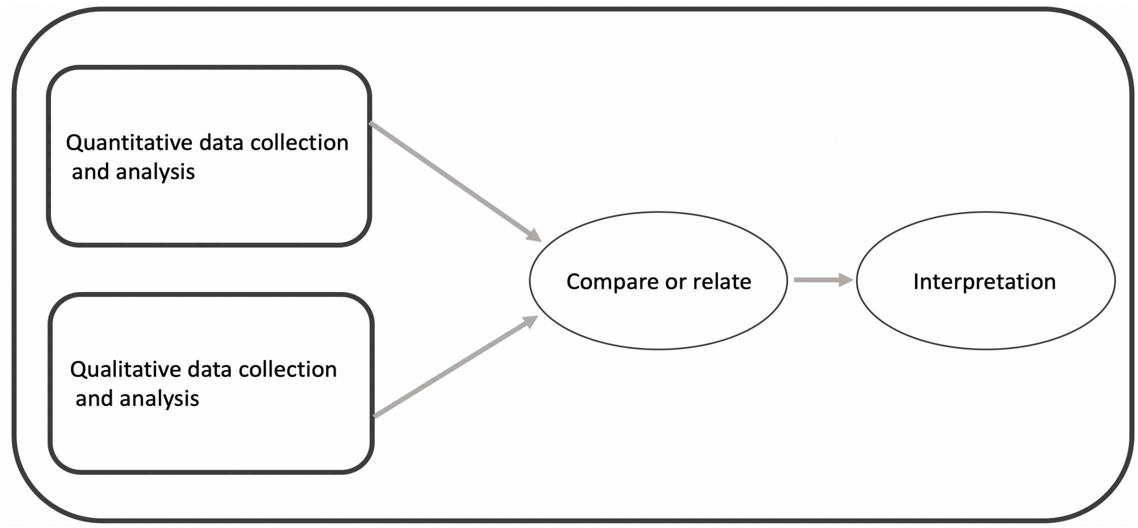

Figure 1. Convergent mixed-methods design (Creswell 2012, p. 541)

Table 1. Project alignment

Research Questions	Research Design	Constructs	Data Collection	Data Analysis
1.How does the multidisciplinary aspect of the 3BYX0P – CBL Systems and Control course affect students?	Mixed-methods research Convergent parallel design	Students' competencies to work in multidisciplinary teams Students' learning and academic achievement	Survey, student and teacher interviews, and observations Student and teacher interviews, course grades and student artefacts	1a.Analyze side by side, then 1b.Compare results 2.Joint display for extremes Data analysis in convergent parallel designs (Creswell, 2012) First cycle and second cycle coding (Miles & Huberman, 2014) Statistics using SPSS (Field, 2013)
2.What are the elements of multidisciplinary teams that foster student learning?	Qualitative research Case study design	Elements that foster learning in multidisciplinary teams	Student and teacher interviews and observations	Qualitative data analysis (Miles & Huberman, 2014)

Regarding the second research question of the project, a case study design is adopted where the case is the "3BYX0P-CBL Systems and Control" course (Fraenkel, Wallen, & Hyun, 2012). In an attempt to understand the potential elements that facilitate multidisciplinary teamwork, noticeable patterns will be identified out of qualitative data from observations and interviews.

Although this report describes the complete set of work packages and tasks planned for the whole project, the report includes findings in relation to the first two work packages described below.

3.2. Work Packages

Table 2 outlines the five work packages (WPs), associated tasks (T), deliverables (D) and their estimated time frame. WP1 mainly addresses the management meetings where plans for progress are discussed. As T1.1 and T1.2 differentiates, the meetings were held between the research team as well as with the teacher team. The constant contact with the teachers of the course; "3BYX0P-CBL Systems and Control" during T1.2 facilitated: a) an overall rapport and open communication between the research team and the teacher team, b) frequent discussions regarding the planning and implementation of the project leading to several improvements, and c) making the project goals and the WPs more visible and accessible to the teachers and the students. The documents shared with the teachers to communicate the project goals and progress included Powerpoint presentations, a Project Guide and documents uploaded to the course Canvas under the specified module; "Background Information Regarding Research". Appendix A and Appendix B illustrate sections of the Project Guide and the Project Information Document shared with the students on the Canvas module; "Background Information Regarding Research" respectively.

Another output of the frequent contact with the teachers was an "Introduction Activity" designed for the first week of the course. The design and execution of this short activity aimed to: a) present the project goals and the value of data collection to the students, b) to reflect a positive attitude and openness to the students, and c) facilitate students' recognition of the multidisciplinary aspect of the course which is the main focus of the research project. The outline of the activity is presented in Appendix C. T1.3: constant investigation of the relevant literature was the final task for WP1.

Table 2. Project progress

		Estimated time frame
WP1	**Management and Planning**	Duration of the project
T1.1	Regular meetings with the researchers, weekly meetings with the supervisor	
T1.2	Regular meetings and collaboration with the teacher team	
T1.3	Literature review	
WP2	**Preparation**	February-April, 2021
T2.1	Development of D1: interview protocols and D2: observation protocol	
T2.2	Preparations for survey adaptation. D1: expert review results, D3: cognitive interview results, and D3: piloting results	
T2.3	Data analysis and interpretation for survey adaptation. D1: adapted survey	
WP3	**Data collection at the course context; "3BYX0P- CBL Systems and Control"**	April-July, 2021
T3.1	Quantitative data. D1: pre-post survey data	
T3.2	Qualitative data. D2: audio recordings of interview data, D2: video recordings of observation data, and D3: student artefacts	
WP4	**Data analysis and interpretation**	August-October, 2021
T4.1	Separate analysis of quantitative and qualitative data. D1: data analysis results	
T4.2	Interpretation, comparison of results with focus on extremes. D1: data interpretation	
WP5	**Dissemination and Communication**	Duration of the project
T5.1	Submitting scientific papers. D1: submit article 1, D2: submit article 2, D3: interim mid-report, D4: interim final-report	
T5.2	Conference presentations. D1: presentation at SEFI2021 and D2: presentation at another international conference	
T5.3	Practical outcomes and outreach. D1: a presentation to the teachers, D2: revised 4TU project Innovation Map, and D3: a poster illustrating only the practical take-away messages	

WP2: Preparation includes three tasks. The participants of the separate Tasks and the related data collection procedures are detailed in the upcoming sections of this report. T2.1 concentrated on the development of three data collection tools to be able to collect data during WP3. These were: a) student interview protocol, b) multidisciplinary teamwork observation protocol, and c) teacher interview protocol. The three data collection tools are presented in Appendices D, E, and F. Both interview protocols were aligned in that they included items that could tap on participants' thinking on similar content. The interview questions were created by the researchers considering three factors (See Appendices D and E): a) the research questions and the constructs investigated in the project (See Table 1), b) literature findings, c) the alignment between the data collection tools; interview protocols, observation protocol and the survey, and d) inclusion of open-ended questions coupled with

verbal probes. The student interview protocol and the teacher interview protocol were composed of three sections each focusing on a different construct explored in this project: a) students' capacities to work in multidisciplinary teams, b) students' learning of the course content, and c) elements that foster learning in multidisciplinary teams (See Table 1). The observation protocol (See Appendix F) is prepared to guide the investigation of multidisciplinary teamwork in its natural context. The observation protocol concentrated on two general categories. The first category; the nature of multidisciplinary learning in teams focuses on how students work on the challenge as a multidisciplinary team. The sub-categories; identification, recognition and integration that also appear in the interview protocols are grounded on the survey factors (Schaffer et al., 2012) currently being adapted in T2.2. The second category of the observation protocol; potential facilitators of multidisciplinary teamwork includes four sub-categories: a) the content of the challenge/project, b) the learning environment, c) teaching elements, and d) team elements (Almajed et al., 2016; Butler et al., 2019; Spelt et al.; 2009, 2015). These sub-categories are also reflected in the interview questions that explore factors that enhance multidisciplinary teamwork. To summarize, the interview protocols, the observation protocol and the survey items are aligned to be able to respond to the goals of this research project collectively.

T2.2 was concerned with adaptation of an existing survey at the TU/e context before its implementation in the "3BYX0P-CBL Systems and Control" course during WP3. The rationales for the survey adaptation were: a) feasibility concerns regarding development of a new survey, b) the original survey items were developed in a different geographical context; the USA, c) some of the words/phrases did not fit with the purpose of our research and we needed modifications to match our context better, d) the need to test the factor structure, and e) the adaptation can empirically support the use of the survey in our project. Survey adaptation followed multiple steps (Tourangeau, Maitland, Steiger, & Yan, 2020). First the Likert-type survey was located with careful consideration of the literature on higher education, interdisciplinary engineering courses and multidisciplinary teamwork. This investigation resulted in a survey in line with the first research question of the study; "Self-Efficacy for Cross-Disciplinary Team-Learning Survey" by Schaffer, Chen, Zhu and Oakes (2012). The survey is composed of 12 items. Appendix G presents the original survey. The justifications on selection of this particular survey were: a) the original article that describe the development of the survey presented proper statistical information (e.g., high factor loadings, appropriate reliability and validity scores), b) the survey addressed the goals of the study, and c) the survey included a relatively small number of items thus decreasing the risk of overwhelming the students. The authors are contacted regarding the survey adaptation process.

The survey is grounded on three factors (Schaffer et al., 2012): “a) *identification* or the ability to self-identify skills, knowledge, and potential project contributions; b) *recognition* or the ability to recognize the potential contributions of others to the project; and c) *integration* or the ability to synthesize awareness and appreciation of other disciplines and reflect this understanding in design products” (p. 86). The three factors are reflected in the interview and the observation protocols as discussed above. The students are expected to rate their confidence in their abilities with regards to each survey item (See Appendix G).

First, the researchers made a few modifications on the items in line with the project goals before proceeding further. This was followed by: 1) receiving expert reviews, 2) conducting cognitive interviews with students as a form of laboratory methods and finally, and 3) conducting a small-scale piloting of the revised survey as a form of field methods (Tourangeau et al., 2020). In order to receive expert reviews, a “Quality Appraisal Form” shown in Appendix H was constructed by the researchers. Next, a “Cognitive Interview Protocol” shown in Appendix I was created to use in short interviews with students that resemble the potential future takers of the survey. The survey items were then revised following the findings of the expert reviews and cognitive interviews. Finally, a pilot study is being conducted with the revised survey with the goal of identifying possible areas for improving the items (Fraenkel et al., 2012). The survey adaptation will later be finalized with T2.3: the analysis of the data collected at the pilot study. We will shortly analyze the pilot data with Factor Analysis using the software SPSS. Once this step is complete, we will use the adapted survey for our pre-assessment in the context of the course. The scheduled date for this pre-administration is May 6th.

WP3 describes the Tasks in association with the data collection and analysis in the context of the CBL course; “3BYX0P-CBL Systems and Control”. The course is built around a real-world challenge that draws on the knowledge from two disciplines: AP and ME. The course syllabus contains the following information: “Small interdisciplinary (both Mechanical Engineering and Applied Physics students) teams of students pick up a real-world control challenge and define relevant requirements and specifications for the system at hand.” The course evaluation includes a group grade (50%) and an individual grade (50%). Some of the assignments and tasks to be graded include peer-review, individual presentation, group product and a midterm. The learning outcomes of the course reflect an interdisciplinary course design; an integrated approach rather than having separate learning outcomes for the disciplines; AP and ME. The core aspect of the course is that the AP and ME students will work in multidisciplinary teams of six.

As indicated by T3.1, the pre-post quantitative data will be collected using the adapted version of the survey with WP2. The qualitative data will be collected using the interview protocols and the observation protocol that are created during WP2: Preparation. The qualitative data will include audio recordings of the interview data and video recordings of the observation data. The observations will focus on students' teamwork during course hours. With WP4: Data analysis and interpretation, first the quantitative survey data and the qualitative data will be analyzed separately. Later the results will be compared for interpretation (See Table 1). Finally, WP5: Dissemination and Communication includes three Tasks that concentrate on writing scientific papers, presenting at scholarly conferences and communicating the practical outcomes.

3.3. Data Collection

Data is currently being collected during WP2 and WP3 of the project (See Table 2) in multiple stages. Table 3 below demonstrates the data collection procedures for the whole project including WP2 and WP3.

Table 3. Data collection procedures

Status	Method	Tool	Participants
WP2: Preparation			
Complete	Expert review	Quality Appraisal Form	7 experts
Complete	Cognitive interviews	Cognitive Interview Protocol	6 Bachelor students at TU/e
In process	Piloting	Revised Survey	30 Bachelor students at TU/e
WP3: Data collection at the course context; CBL 3BYX0P-Systems and Control			
May and July, 2021	Pre-post survey	Adapted survey	30 students taking the course; 7 AP students and 23 ME students.
July, 2021	Student interviews	Student Interview Protocol	10 of the students taking the course
July, 2021	Teacher interviews	Teacher Interview Protocol	The teachers and the tutors responsible for the course
4 times during the course	Observations	Observation Protocol	2 of the 5 multidisciplinary teams

The left column shows the status of each data collection procedure. The remaining section of this report only describes the data collection and data analysis procedures of T2.2: Preparations for survey adaptation that are now complete: expert reviews and cognitive interviews. The Ethics Approval Letter had been received prior to data collection.

The expert reviews were collected from seven individuals. The group of experts included the teachers and colleagues responsible for the delivery of the course (n = 3); lecturers from the Eindhoven School of Education (n = 2), and two other professionals who hold a Ph.D. on curriculum and instruction. The Quality Appraisal Form (See Appendix H) had been created by the researchers based on the components by Tourangeau et al. (2020) and Olson (2010). The experts were instructed to provide their opinions and recommendations separately for each item based on the six codes that appeared on the Quality Appraisal Form:

> **"a. Burdensome**—Item requires a great deal of cognitive work by the student. There are problems related to communicating the intent or meaning of the item to the student.
> **b. Clarity**—There are unclear technical terms, some phrases are undefined, unclear, or complex. Vagueness, there are multiple ways to interpret the question or to decide what is to be included or excluded. Issues with wording, item is lengthy, awkward, ungrammatical, or contains complicated syntax.
> **c. Sensitivity/Bias**— Sensitive nature or wording, and for bias. The question asks about a topic that is embarrassing or private. There is sensitive wording.
> **d. Double-Barreled**— Item contains more than one implicit question.
> **e. Knowledge/Attitude**—The students are likely to not know or have trouble remembering information being asked. Assumed attitude may not exist, student is unlikely to have formed the attitude being asked about.
> **f. Other problems**—Other problems not previously identified."

The final part of the Quality Appraisal Form included open-ended questions for the experts to report their overall comments. The form was e-mailed to the experts individually together with the survey. Next, cognitive interview results were conducted with the goal of further improving the quality and psychometric properties of the survey. The following underlines the value of cognitive interviews in adapting surveys: "the administration of draft survey questions while collecting additional verbal information about the survey responses, which is used to evaluate the quality of the response or to help determine whether the question is generation the information that its author intends" (Beatty & Willis, 2007, p. 287). The cognitive interview protocol (See Appendix I) included an introduction that provided the students with the goals of the interview and the instructions. The researchers used the think-aloud questions and the verbal probes interchangeably throughout the interview. In total, six students from multiple engineering and departments participated to the interviews. Two of the interview sessions were conducted with participation of two students together. A third interview session was conducted with a single student. The interview sessions lasted 20 minutes on average. The researcher took field notes during the interviews.

Finally, for T2.2: Preparations for survey adaptation, a small-scale pilot is currently carried with TU/e Bachelor students from multiple science and engineering fields. Data is collected using Google Forms. The online survey is shared in the course Canvas of two different TU/e courses. Currently we have received 15 responses and more responses are coming in. The factor analysis results will be shared in a different project report.

Considering the participants involved in the expert reviews and the cognitive interviews, a combination of convenient sampling and snowball sampling were adopted (Fraenkel et al., 2012). We used our professional personal networks to access the participants. Second, certain criteria were identified in line with the goals of the study. For expert interviews, the criteria applied was having experience with both survey development and interdisciplinary learning environments. For cognitive interviews, the students were contacted during researcher's visits to one of the Q3 courses of one of the teachers involved in this project. In addition, the criteria to include the students from this particular course was having prior experience in multidisciplinary teams.

3.4. Data Analysis

To analyze the data collected from the experts using the Quality Appraisal Form, a descriptive analysis was conducted (Fraenkel et al., 2012). Firstly, all responses were collectively put to a single form for a holistic view. The items that did not receive any feedback were not considered. A summarization of experts' comments and recommendations were organized for separate items. Following an initial examination, commonalities for each item were specified. In order to reach a summary of the commonalities, two categories were defined: a) general comments and b) item-specific comments. Comments were considered against the two categories. Based on the commonalities in expert responses, modifications were completed. These modifications were sometimes directly recommended in the expert reviews and at times decided by the researchers based on the experts' comments and warnings.

For the analysis of the data collected with cognitive interviews, field notes were used as the data source. First, similar to analyzing the expert reviews, field notes considered each item were put together in a single file. The qualitative data was examined using a combination of the data analysis models for cognitive interviews suggested by Willis (2015, p. 60) and Ackerman and Blair (2006). Accordingly, the four data analysis steps were: 1) initial screening of data, identification of general categories, 2) finalize categories based on their repetition; dominant and/or repeated categories were identified and presented with quotations, and 3) revisions to the items based on the categories and discussions among the researchers.

4.Results

This report includes the findings in relation to T.2.2: Preparations for survey adaptation (See Table 2) that are now complete: 1) expert reviews and 2) cognitive interviews (See Table 3).

The modifications to the original survey items (Schaefer et al., 2012) before proceeding with the expert reviews and cognitive interviews were: 1) adding instructions, 2) changing the response options from “1-100” to “Not confident at all-Absolutely confident”, 3) adding a demographics section asking for gender, department, and prior experience in teams, 4) changing past tensed phrases to present tense to be appropriate for the pre-administration e.g., “contributed” to “can contribute”, 5) using “team mate” instead of “others from different disciplines” to be more in line with the project focus.

4.1. Expert Review Results

Each expert had reported their comments and recommendations separately on the Quality Appraisal Form. After merging all reviews in a single file, data was summarized descriptively using reviewers’ comments and recommendations on the form. During this summarization process, two categories were used as shown in Table 4 below: a) general comments and b) item-specific comments. According to the commonalities and repetition in the experts’ reviews, multiple modifications were made.

The first category; *General comments* was first concerned with clarity of the two phrases: “disciplines” and “design”. As can be seen in Table 4, these phrases were changed for improved clarity. Considering consistency, it was reported that the whole survey should be consistent in using the same phrases and that the phrase “cross-disciplinary” could be confusing for the students. One of the comments highlighted: “…be clear in your terminology by using the same words over and over again”. As a result of such comments, “cross-disciplinary team-learning” was removed from the survey instructions.

Table 4. Expert review results

General Comments	Responses/Revisions
Clarity	"academic disciplines" to "disciplines" "design" to "project"
Consistency	Phrase removed: "cross-disciplinary team learning"
Authenticity	"In this course, you will work in a multidisciplinary team" to "In this course, you will work in a team of six students." Removed: "chemistry, computer science" Removed: "at least" Removed: e.g., "you will start working" changed to "you will work"
Item-Specific Comments	**Responses/Revisions**
Clarity	"clearly identify" to identify for Item 1 "appropriately assess" to assess for Item 2 "accurately assess" to assess for Item 3 "accurately evaluate" to evaluate for Item 4 "clearly identify" to "identify" for Item 5
	"identify the type of knowledge and skills" to "identify the knowledge and skills" for item 5
	"accurately recognize goals that reflect the disciplinary backgrounds of other team members." to "accurately recognize the goals of my teammates who come from another disciplinary background" for item 6

To continue, authenticity expressed the experts' common insight that it is better to use specific terminologies unique to the course content in the survey instructions, rather than general statements. Following up on this comment, one sentence was refined and three phrases that were unrelated to the course context were removed. The next category; *Item-specific* comments focused on the clarity of specific items addressed by the experts. As reported on Table 4, the adjectives e.g., appropriately, accurately were removed. Finally, two items were modified for a more concise expression.

4.2. Cognitive Interview Results

As the first step, three general categories emerged as the researcher's field notes were read multiple times: a) instructions, b) items, and c) response formation (Ackerman & Blair 2006; Willis, 2015). These categories were used to summarize the data and to decide on revisions to the survey. The first category; *Instructions* included two codes. For *consistency*, it was revealed that the students were confused about the text including two similar constructs; multidisciplinary and cross-disciplinary. As a result, the sentence: "Part-II aims to assess self-efficacy in cross-disciplinary team learning." is now removed so that the whole survey focuses on multidisciplinary teamwork. For *clarity*, the students reported that the instructions including italics font and use of brackets together made it difficult for them to follow. Furthermore, comments focused on the fact that bold letters would draw more attention. In line with this, the phrase "…will work in a team of six students" was changed to a non-italic font and now it is written in bold. Next, the two disciplines; AP and ME are not written in brackets now.

The second category; *Items* underlined students' reflections and comments for specific items. Five items in total were discussed for a possible improvement by at least two of the students. Item 4 formerly read: "…evaluate how much my knowledge and skills can contribute to the project." It was revealed that using: "contribute" in this item was confusing for the students. Item4 is revised to a simpler version now: "…evaluate how I can use my knowledge and skills in the project."

To continue, originally item 7 read: "… discuss contributions those from other disciplines can make to the project." The common comment was that the item should is short but still not very clear. One student reported: "I had to read this item three times." Upon these reflections, the item was revised as: "…discuss the contributions of my teammates to the project who come from another disciplinary background." Item 12 originally was as follows: "…examine a design issue from my teammate's perspective". It was found that the students considered the work "design" as redundant and thus confusing. As a result, the item was modified as: "…examine an issue from my teammates' perspective." For the items; item 3 and item 4, three of the students reported that these two items are alike and that they had a challenge in distinguishing the content of the items. Currently these items are retained in their original form however a final decision will be taken following the factor analysis results of WP2 (See Table 1).

For the third category; *Response formation*, majority of the respondents reported not having difficulty selecting a response from the options provided. Therefore, the response category for the survey was retained as ranging from "Not confident at all" to "Absolutely confident".

Finally, putting the survey instruction: "please rate your confidence in your current ability" separately to each item, revising the response categories as ranging from "strongly agree" to "strongly disagree" and the challenge in understanding whose goals are referred to by item 6 were among the less frequently discussed concerns.

5.Discussion

This report introduced the "Deepening Multidisciplinarity within Systems & Control Project" granted by the Innovation Fund. The goals of the project, conceptual background and the procedures followed are presented in this report. Focusing on the multidisciplinary teamwork aspect of the course; 3BYX0P-CBL Systems and Control Project, this project investigates the perceptions and experiences of the students regarding their learning and competencies to work in teams. The potential elements that foster the functioning of multidisciplinary teams for enhanced student learning is also explored. The results can improve our understanding of how multidisciplinary teamwork in a CBL course can be supported. The outcomes of this project have the potential to contribute to interdisciplinary engineering education, design of CBL environments and how students function and learn in multidisciplinary teams.

As discussed, the researchers have worked on WP1: Management and Planning and WP2: Preparation so far (See Table 2). The data collections tools; Student Interview Protocol, Teacher Interview Protocol, and Multidisciplinary Teamwork Observation Protocol are now finalized. The Likert-type survey that will be used as a pre-post assessment is currently being adapted. The adaptation procedure included: 1) receiving expert reviews, 2) laboratory methods; cognitive interviews, and 3) field methods; conducting a small-scale piloting of the revised survey (Tourangeau et al., 2020). The expert reviews and the cognitive interviews resulted in minor modifications to the survey items. To summarize, the modifications included concerns with communicating the intent or meaning of an item or a phrase (e.g., cross-disciplinary), redundancy and simplicity (e.g., using shorter and more concise expressions), consistency; using the same expressions throughout the survey, and authenticity (e.g., using the students' actual departments in survey instructions). Currently the researchers are receiving student responses for the piloting. The next step is now to analyze the pilot results and arrive at the adapted version of the survey for our own research context. The quantitative survey data collected during the piloting will be analyzed with factor analysis using the SPSS software to understand the psychometrics of the adapted survey (Field, 2013; Tourangeau et al., 2020).

An important aspect of the project has been the continuous contact with the teacher team of the course; 3BYX0P-CBL Systems and Control Project. This contact resulted in constant collaboration with the teachers, building a separate module for the project on course Canvas and an introduction activity to communicate the project to the students and to establish rapport.

The full findings of this project will be used in improvement of the course; 3BYX0P-CBL Systems and Control Project and in design of similar courses. The findings will be disseminated through; a) TU/e interim reports, b) a presentation for teachers focusing on recommendations for practice, c) articles in scholarly journals, d) presentations at academic conferences, and d) a poster illustrating the practice-oriented take-away messages.

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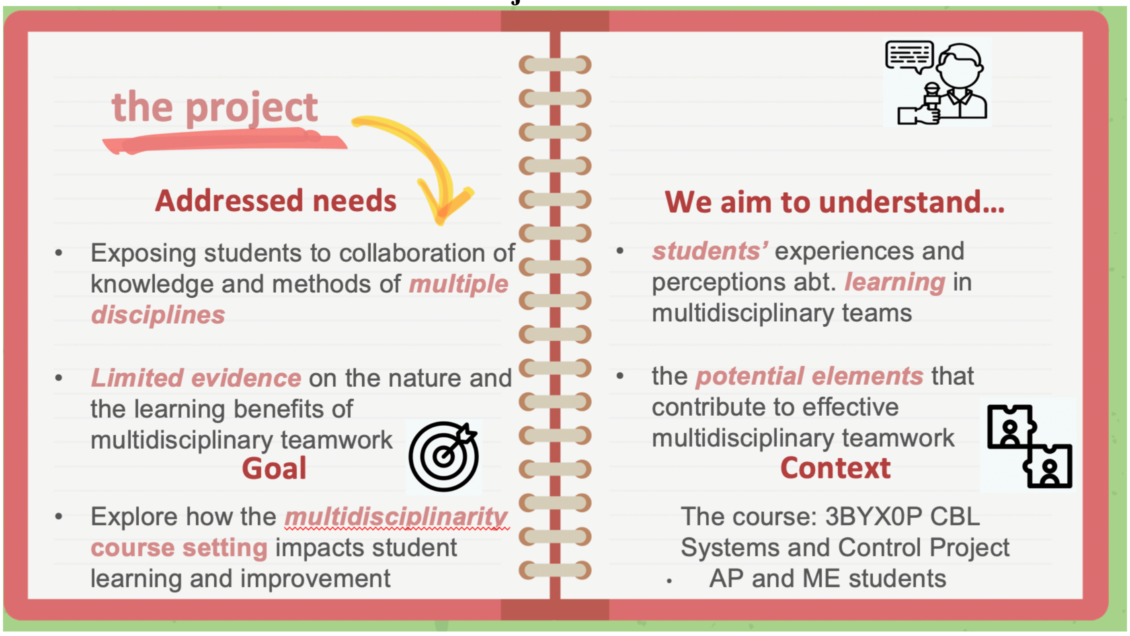
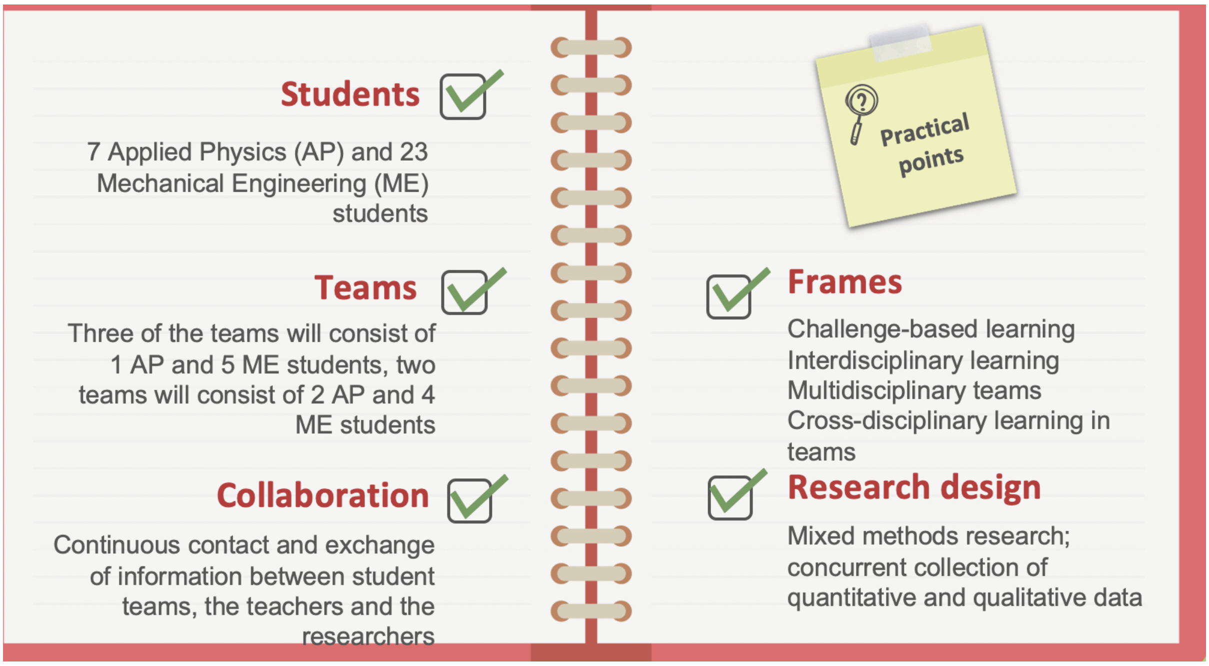
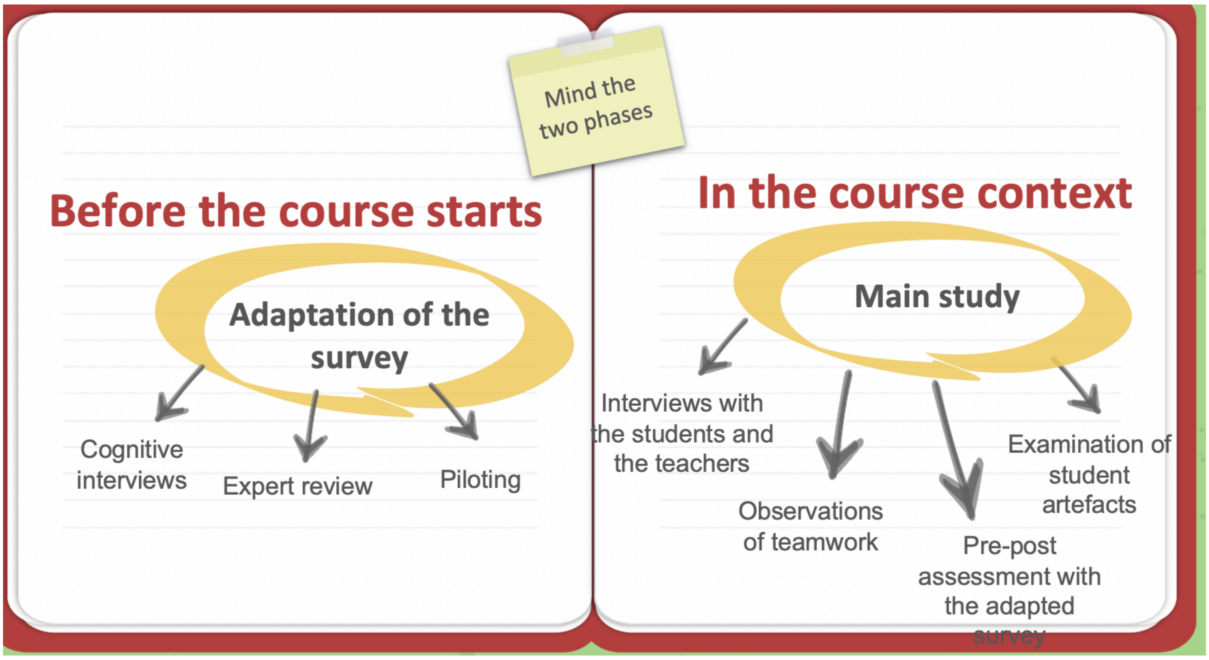
APPENDIX A
Project Guide






Rationales for the project
We want to understand the multidisciplinary setting of the course in relation to student learning and improvement
Need for empirical evidence
Comprehensive examination of learning in a multidisciplinary setting
Existing assessment issues
Assessment of student learning and improvement in interdisciplinary settings is underdeveloped
21st cc. needs/TU/e strategy 2030
Attention to interdisciplinary coursework and benefits of multidisciplinary teams


Mind the two phases
Before the course starts
Adaptation of the survey
Cognitive interviews
Expert review
Piloting
In the course context
Main study
Interviews with the students and the teachers
Observations of teamwork
Pre-post assessment with the adapted survey
Examination of student artefacts

APPENDIX B
Project Information for Students

Deepening Multidisciplinarity with

3BYX0P CBL Systems and Control Project / **Q4**

Background to the Project

In TU/e's educational vision towards 2030, **challenge-based learning** plays a crucial role. Exposure to **the knowledge and methods of different disciplines** in solving real-world challenges provides opportunities for facilitating students' learning and development.

Our project focuses on **the unique setting of the course**; "3BYX0P-Systems and Control" that integrates two disciplines; Applied Physics and Mechanical Engineering.

Project Goals

To investigate…

…students' perceptions and experiences about their learning and improvement **in multidisciplinary teams**

…the factors that facilitate multidisciplinary teamwork.

Collecting Information

By participating, you will contribute to the project achieve its goals. Your valuable time will support design of similar courses at TU/e.

On voluntary basis, we plan to collect information using the three tools below:

A short survey	Individual interviews	Observations
On May 6th & in June To be available in class and online	Last three weeks of the course	Four times through the semester Two teams to be observed

APPENDIX C
Activity Outline

- **Context:** 3BYX0P CBL Systems and Control Project, Q4
- **Responsible Teacher:** Canan Mesutoglu; Post-doc, Eindhoven School of Education
- **General Overview:** Multidisciplinarity is one of the core characteristics of challenge-based learning environments together with global themes, technology, flexibility and real-world challenges. As students work in multidisciplinary teams towards solving a challenge, they reflect the content and methods of their own discipline and also appreciate their team members' disciplinary background. This activity is planned to orient the students towards the value of multidisciplinary team work for a challenge-based course and also for societal improvements in the 21st century.
- **Objectives:** The students will be able to:
  - Recognize the value of multidisciplinary team work
  - Gain appreciation of one of the critical components of this course; multidisciplinary team work
- **Duration:** 25 minutes (X2)
- **Materials:** Team worksheets, Powerpoint presentation, laptop and projector, post-its
- **Participants:** 6 students in each of the 5 teams ($n = 30$)
- **Preparation:** The teacher brings the worksheets and post-its to the classroom. The laptop and the projector are prepared.

1. **Phase 1: Engage (grabbing attention): (5 min.)**
   - The Big Brain Theory is a television show that was shown on Discovery Channel in 2013. The contestants work in multidisciplinary teams to solve a different design challenge in each episode. This phase of the activity starts with asking if the students heard of this show or any similar programs. Then a short video from the show is shared with the class that focus on the disciplines of the team members (e.g., product designer, mechanical engineer, software engineer) and their collaboration on one of the challenges. At the end of the video, 1-2 questions are asked to the class e.g., "what was an interesting point for you in the video?"
2. **Phase 2: Explore (the activity sheet): (8 min.)**
   - The students will work in their teams. Three activity sheets are distributed to each team. The activity will be completed in pairs.
   - The sheet introduces a short scenario of a real-world challenge, some of its features, and the disciplines of the people in the multidisciplinary team who will work together to solve the challenge.
   - Now the students are asked to: 1-create a similar challenge scenario, 2-brainstorm/research and identify which disciplines might best work together.
   - In order to initiate students' work, two cups filled with small folded papers will be used. The first cup includes alternatives for a big idea (e.g., climate change, clean water) and the second cup includes alternatives for timeline and budget. Each pair will select one folded paper from the two cups. Based on these choices, they will complete the instructions.
3. **Phase 3: Explain (teachers' providing information): (5 min.)**
   - The teacher will first ask 1-2 volunteer pair(s) to share their work.
   - Then the teacher will do a very short presentation of 2-3 slides. This will contain: 1-similar real-world scenarios, and 2-what team members usually do in the multidisciplinary teams.
4. **Phase 4: Elaborate (continue the activity sheet): (4 min.)**
   - The second page of the activity sheet will contain authentic quotations from people who have been involved in multidisciplinary teams (e.g., reflecting what they did, some advantages and also challenges). The pairs will be asked to select two of these quotations that they think might reflect their opinion towards multidisciplinary team work at the end of this course.
5. **Phase 5: Evaluate: (personal reflections): (3 min.)**
   - Individual work; the students will use one of the colorful post-its to write one take-away sentence to a friend who missed this session.

APPENDIX D
Student Interview Protocol

The interviews aim to explore your experiences and perceptions regarding interdisciplinary courses and working in multidisciplinary teams. By participating in the interviews, you are contributing to our research project achieve its objectives. *Your responses will only be used* for research purposes. Thank you for providing your valuable insights.

Thank you for your help to improve the research and practice efforts at TU/e.

Canan Mesutoglu, c.mesutoglu@tue.nl,
on behalf of the "Deepening Multidisciplinarity with Systems and Control" Project Team
Eindhoven School of Education

Department: ……………………………

Part-I

Part-I aims to investigate your experiences in working in multidisciplinary teams.

1.Students in multidisciplinary teams come from different disciplinary backgrounds. They connect their discipline to interdisciplinary challenges, learn from each others' perspectives and produce work through a process that would not have been possible in a mono-disciplinary team setting. From 0 to 5, can you rate how well you performed as a multidisciplinary team?
Please explain why you decided at the level indicated?

2. Now please consider your progress through this course where you worked on the assigned challenge as a multidisciplinary team. Compared to the first weeks of the course, how do you describe your current confidence to work with team members from different disciplines on a given challenge?
How did you arrive at this conclusion? How do you realize your improvement to work in multidisciplinary teams?

Now we will further focus on the possible changes you recognize in your competencies to work in multidisciplinary teams. Once again, please consider your progress through this course.

3a. Is there a difference in your ability to identify the potential contributions of the concepts and methods of your discipline to a given challenge/project?
Can you elaborate on your response? How about your ability to discuss your contributions to the project, at the end?

3.b. How has participating in this course influenced your ability to recognize how others can influence the quality of a challenge/project in a way that represents their academic disciplines?
Can you elaborate on your response? How about your ability to discuss the contributions they made to the project, at the end?

3.c. Do you agree that now you can now better examine a given challenge/problem from a teammate's disciplinary perspective? *What makes you think so?*
Is there a difference in your ability to talk about the project design using other discipline's language?

3.d. Let's focus on how AP and ME students shared and discussed knowledge and ideas related to the challenge/project. You can think of any of the course weeks.
Think of a moment that you positively contributed to the team bringing a perspective from your discipline. Can you briefly describe?

Think of a moment that a teammate contributed to the team by bringing a perspective from their discipline. Can you briefly describe?
Please provide an example of a time when members of your team drew conclusions considering different disciplinary ideas.

Part-II

This part of the interview will focus on your perceptions on the factors that make multidisciplinary teams perform better.

1.What are some of the factors that you perceive as facilitating your improvement in a multidisciplinary team? Why? You can think of the improvement in:
your learning of the course content
your overall course performance
your confidence to work in a multidisciplinary team
the quality of your challenge/project work

<u>*Prompts for possible facilitators you experienced:*</u>
1.a. The content of the challenge/project; *alignment between the challenge and the disciplines; AP and ME*

1.b. The learning environment
The course curriculum and materials
Assessments
The learning activities

1.c. Teaching elements
Receiving guidance from the teacher/TA
Teacher team of multiple disciplines
Role of a facilitator

1.d. *Team elements*
Personal characteristics and prior experiences
Team work; discussions; understanding and integrating multiple viewpoints
Team commitment; members being prepared and encouraged
Team organization: Clarity in goals, responsibilities and roles
Team structure and size
Communication; feeling recognized and comfortable contributing
Mastery of experience; being able to contribute with their disciplinary background
Team learning behaviors; listening carefully and asking questions

Part-III

This last part aims to investigate the perceived contribution of multidisciplinary team work to your learning in this course.

1.Describe any learning outcomes that resulted of working specifically with team members from other disciplines?

2. How beneficial was the multidisciplinary teamwork to your success and learning in this course?
Please comment with specific examples on whether the multidisciplinary teamwork helped you do well in:
…understanding the content of the course
...grades, assignments, exams

...project report

...others (final presentations,....)

...*please give a specific example that demonstrate how the multidisciplinary team contributed to your learning in this course.*

3.In this course, you worked on the challenge as a multidisciplinary team. Now, please think of how the team members interacted as you worked on this challenge.

How do you explain the quality of your solution to the challenge with regards to working in multidisciplinary teams? How did working in a multidisciplinary team impact the success of your work on the challenge?

4.Is there anything else you would like to share regarding your experience? *Final comments on overall perceptions of:*

multidisciplinary teamwork

interdisciplinary courses

APPENDIX E
Teacher Interview Protocol

The interviews aim to explore your experiences and perceptions regarding interdisciplinary courses and working in multidisciplinary teams. By participating in the interviews, you are contributing to our research project achieve its objectives. *Your responses will only be used* for research purposes. Thank you for providing your valuable insights.

Thank you for your help to improve the research and practice efforts at TU/e.

Canan Mesutoglu, c.mesutoglu@tue.nl,
on behalf of the "Deepening Multidisciplinarity with Systems and Control" Project Team
Eindhoven School of Education

Part-I

Part-I aims to investigate your perceptions regarding students' learning and improvement in this course.

1.Students in multidisciplinary teams come from different disciplinary backgrounds. They connect their discipline to interdisciplinary challenges, learn from each other's' perspectives and produce work through a process that would not have been possible in a mono-disciplinary team setting. From 0 to 5, can you rate how well the students performed as multidisciplinary teams?

Please explain why you decided at the level indicated?

2. <u>Now please consider the students' progress through this course</u> where they worked on the assigned challenge as a multidisciplinary team. Compared to the first weeks of the course, how do you describe their current confidence to work with team members from different disciplines on a given challenge?

How did you arrive at this conclusion? How do you realize their improvement to work in multidisciplinary teams?

Now we will further focus on the possible changes you recognize in the students' competencies to work in multidisciplinary teams. <u>Once again, please consider their progress through this course.</u>

3a. Is there a difference in their ability to identify the potential contributions of the concepts and methods of their own discipline to a given challenge/project?

Can you elaborate on your response? How about their ability to discuss their contributions to the project, at the end?

3.b. How has participating in this course influenced their ability to recognize how others can influence the quality of a challenge/project in a way that represents their academic disciplines?

Can you elaborate on your response?

3.c. Do you agree that now they can now better examine a given challenge/problem from a teammate's disciplinary perspective? *What makes you think so?*

Is there a difference in their ability to talk about the project design using other discipline's language?

3.d. Let's focus on how AP and ME students shared and discussed knowledge and ideas related to the challenge/project. You can think of any of the course weeks.

Please provide an example of a time when members of your team drew conclusions considering different disciplinary ideas.
Bringing perspectives from their own discipline.

Part-II

This part of the interview will focus on your perceptions on the factors that make multidisciplinary teams perform better.

1.What are some of the factors that you perceive as facilitating the students' improvement in a multidisciplinary team? Why?

<u>*Prompts for possible facilitators you experienced:*</u>

1.a. The content of the challenge/project; *alignment between the challenge and the disciplines; AP and ME*

1.b. The learning environment
The course curriculum and materials
Assessments
The learning activities

1.c. Teaching elements
Receiving guidance from the teacher/TA
Teacher team of multiple disciplines
Role of a facilitator

1.d. *Team elements*
Personal characteristics and prior experiences
Team work; discussions; understanding and integrating multiple viewpoints
Team commitment; members being prepared and encouraged
Team organization: Clarity in goals, responsibilities and roles
Team structure and size
Communication; feeling recognized and comfortable contributing
Mastery of experience; being able to contribute with their disciplinary background

Part-III

This last part aims to investigate the perceived contribution of multidisciplinary team work to the students' learning in this course.

1.Describe any learning outcomes that resulted of working specifically with team members from other disciplines?
2. What do you think about the quality of the students' output e.g., grades, reports, presentations, exams, assignments in this course in relation to the multidisciplinary teamwork? …*understanding the content of the course*

…*Please give a specific example that demonstrate how the multidisciplinary team contributed to their learning in this course.*

3. Now, please think back to the first weeks of this course when the students were introduced the challenge and how the team members interacted during that time.

How do you explain the quality of their solution to the challenge with regards to working in multidisciplinary teams? How did working in a multidisciplinary team impact the success of their work on the challenge?

4. Is there anything else you would like to share regarding your experience? *Final comments on the students' overall perceptions of:*
multidisciplinary teamwork
interdisciplinary courses

APPENDIX F
Observation Protocol

Purpose: To investigate multidisciplinary teamwork in its natural context

Two major categories to address:

1) **The nature of multidisciplinary learning in teams:**

    a) *identification*, identifying skills, knowledge, and potential project contributions of one's own discipline

    b) *recognition*, recognizing the potential contributions of other disciplines to the project

    c) *integration*, synthesizing awareness and appreciation of other disciplines and reflect this understanding in design products

2) **The potential facilitators of multidisciplinary teamwork**

    a) The content of the challenge/project; alignment between the challenge and the disciplines
    b) The learning environment
    c) Teaching elements
    d) Team elements

Site Observation Protocol for Taking Field Notes

Pre-Observation

I. BACKGROUND INFORMATION

Date:	Observer:	Start time:	End time:
Location of observation:			
Group name:		Students' disciplines:	Number of students in the group:
Describe the classroom context and the team behaviors briefly. Attach materials if there is any.			

During Observation

II- CONTEXT AND ACTIONS

In the space provided below please give a brief description of the teamwork observed, the team setting in which the activity took place (space, seating arrangements, etc.), and any relevant details about the communication and work on the project and teacher that you think are important. Record here events that may help in reaching the observation goals.

Time	**Description of Events** (Note the instances that address the research questions.)	**Observer notes on the events/ codes** (Note down emerging codes)
	CONTEXT: The team • Who are involved in the team? Describe the observable characteristics of the students.	
	ACTIVITY: The activity/task • What is the topic/goal of the activity/task the students are working on? **The nature of multi-disciplinary learning in teams**, note instances where the team members reflect the below three actions.	

Time	**Description of Events** (Note the instances that address the research questions.)	**Observer notes on the events/ codes** (Note down emerging codes)
	a) *identification* b) *recognition*, c) *integration*,	
	The elements that foster learning in multidisciplinary teamwork, note instances with the realization of certain factors that contribute to students' multidisciplinary work on the project. Note instances for potential facilitators including and extending the below:	
	a) The content of the challenge/project b) The learning environment c) Teaching elements d) Team elements	

APPENDIX G
Cross-Disciplinary Team Learning Self-Efficacy Survey
(Schaffer et al., 2012, p. 86)

	Not confident at all	Slightly confident	Somewhat confident	Confident	Absolutely confident
1. Clearly identify the type of knowledge and skills I have brought to the project.					
2. Appropriately assess the relevance of my knowledge and skills to the project.					
3. Accurately assess the extent to which my mastery of knowledge and skills was adequate for the project.					
4. Accurately evaluate how much my knowledge and skills contributed to the project.					
5. Clearly identify the type of knowledge and skills possessed by team mates from other disciplines.					
6. Accurately recognize goals that reflect the disciplinary backgrounds of other team members.					
7. Discuss the contributions other disciplines have made to the project.					
8. Think of ways other members have influenced the project in a way that represents their academic disciplines.					
9. Talk about the project design using other discipline languages.					
10. Provide input to others from different disciplines.					
11. Be proactive in working on design problems with those from different disciplines.					
12. Examine a design issue from my teammate’s perspective.					

APPENDIX H
Quality Appraisal Form

Helping the students develop their abilities to work with others from different academic disciplines is an important objective of TU/e. This survey aims to explore students' confidence level related to working with others in a multidisciplinary team and their perceptions towards interdisciplinary learning. We need to ensure the survey items work successfully in our research context before we proceed with the actual implementation. We will use *this Quality Appraisal Form* to collect your reflections on the quality and appropriateness of the survey items. Therefore, *your responses will only be used* in making modifications to this survey for improved psychometric properties.

Please do not write your name on this survey.
Thank you for your help to improve the research and practice efforts at TU/e.

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on behalf of the "Deepening Multidisciplinarity with Systems and Control" Project Team
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Introduction

Experts reviews are collected to gain a general view of adapted or newly developed survey items and to identify potential problems based on principles such as item structure, cognitive load, sensitivity and the impact of format and layout of the items.

On the pages 2 -3, you will find the survey items. This survey will be used to collect data from the Applied Physics and Mechanical Engineering students who will take the course: "Systems and Control". The survey includes two parts: a) Part-I: Cross-disciplinary learning in teams, and b) Part-II: Perceptions towards interdisciplinary learning. Part-I aims to assess students' self-efficacy in cross-disciplinary team learning and Part-II aims to assess students' perceptions about the importance and usefulness of interdisciplinary study and the possible drawbacks of interdisciplinary learning.

Instructions for Providing your Expert Review

Using the spaces provided on the tables on pages 2-3, please write down your reflections considering the below *codes from a to f*. Here you will find a short explanation for each code.

a. Burdensome—Item requires a great deal of cognitive work by the student. There are problems related to communicating the intent or meaning of the item to the student.
b. Clarity—There are unclear technical terms, some phrases are undefined, unclear, or complex. Vagueness, there are multiple ways to interpret the question or to decide what is to be included or excluded. Issues with wording, item is lengthy, awkward, ungrammatical, or contains complicated syntax.
c. Sensitivity/Bias— Sensitive nature or wording, and for bias. The question asks about a topic that is embarrassing or private. There is sensitive wording.
d. Double-Barreled— Item contains more than one implicit question.
e. Knowledge/Attitude—The students are likely to not know or have trouble remembering information being asked. Assumed attitude may not exist, student is unlikely to have formed the attitude being asked about.
f. Other problems—Other problems not previously identified.

For each item in Part-I and Part-II, if you think the item can be used as it is, put a mark (e.g., X, check) in the first column. If not, then just put the code(s) you find associated with this item. Finally, please provide a brief statement to explain your thinking.

Survey Items

Instruction for the student: The survey aims to assess self-efficacy in cross-disciplinary team learning.

Now please *imagine yourself in a multidisciplinary team of five students*. Your teammates come from at least two different disciplinary backgrounds (e.g., applied physics, chemistry, computer science, mechanical engineering). In your team, you will start *working together* on your assigned team project.

Part-II contains 12 items presented in the table below. The response options range from "Not confident at all" to "Absolutely confident". Please put a mark (e.g., X, check) for the response option you choose for each item. For each item, please rate your confidence in your current ability to…"

	Can be used as it is	**Suggestion of revision with the code(s) assigned**	**Brief comment considering selected code(s)**
1. Clearly identify the type of knowledge and skills I have brought to this project.			
2. Appropriately assess the relevance of my knowledge and skills to this project.			
3. Accurately assess the extent to which my mastery of knowledge and skills was adequate for the project.			
4. Accurately evaluate how much my knowledge and skills contributed to the project.			
5. Clearly identify the type of knowledge and skills possessed by team mates from other disciplines.			
6. Accurately recognize goals that reflect the disciplinary backgrounds of other team members.			
7. Discuss the contributions other disciplines have made to the project.			
8. Think of ways other members have influenced the project in a way that represents their academic disciplines.			
9. Talk about the project design using other discipline languages.			
10. Provide input to others from different disciplines.			
11. Be proactive in working on design problems with those from different disciplines.			

12. Examine a design issue from my teammate's perspective.	

Final Comments

1.Is the survey compatible with the content of the course: "Systems and Control"? Is, yes, please specify to what extent and how the survey deviates from the course content.
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2.Does the design of the questionnaire contain a well-considered sequence of the items? If no, please explain your answer.
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3. Please consider any potential problems with the instructions of Part-I and Part-II from the students' point of view. Are the instructions clear? What do you think? Are there any conflicting or inaccurate instructions?

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4. Any other insights that you would like to share.

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APPENDIX I
Cognitive Interview Protocol

Welcome

Greetings. Expressing an appreciation of the time and personal insights of the interviewee. Rapport and open atmosphere is established.

The goals are clarified for the interviewee: a) the objectives of the "Deepening Multidisciplinarity with Systems and Control" project at TU/e, b) the importance of adapting surveys that were developed in different contexts, and c) the goals and procedures of cognitive interviews in relation to survey quality improvement.

The interviewer reads: "I am interested in what you think about the items in this survey as we go through the items together. We are trying to investigate a number of aspects about the quality of the items that are related to: a) clarity (wording, technical terms, vagueness), b) reading (missing information, parts of the item), c) instructions that guide the survey taker, d) response categories, e) knowledge/memory (item requiring factual information, recall failure, attitude), f) ordering of items, and g) other potential issues you want to raise. I will be asking some questions that will help you consider the mentioned aspects. As we examine each item separately, please provide a response category of your own choice. If you reject to provide an answer to a certain item, please feel free to. Please ask about any unclear instructions." The interviewee is provided with a copy of the survey items.

Interview Questions

Think Aloud Questions

- Please tell me everything you are thinking as we read the instructions of this survey.
- Please tell me everything you are thinking as you answer this item.
- What are you thinking now, as you read the item?
- What were you thinking about what the item is asking from you?
- What is this item asking?

Verbal Probes

- What to you is X (e.g., interdisciplinary study)?
- Is this item clear to you? Can you paraphrase what this item is asking?
- How did you decide to choose this response category?
- What does X (e.g., interdisciplinary curriculum) mean to you? How did you remember that?
- Can you tell me more about that?
- Can you repeat the item I just asked in your own words?
- Was the intent of the item clear? If not, how can clarity be improved?