

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 January 2022. 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). Learning environments that address multiple disciplines can 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). Interdisciplinary learning environments help students appreciate multiple disciplinary perspectives through informed collaborations (Knobloch et al., 2020).

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-Avenidaño, 2020). 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, b) the development of similar courses, and c) researchers in the field.

2. Conceptual Framework

2.1. Challenge-Based Learning

TU/e's 2030 vision statement 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). 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). 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). 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 multidisciplinary that advocates collaboration of multiple disciplines as the students work on challenges together.

2.2. Multidisciplinary Teamwork

There are 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 multidisciplinary 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). 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).

In order to enhance multidisciplinary teams, it is helpful to have an understanding of the potential facilitators of multidisciplinary teamwork. The functioning of multidisciplinary teams is primarily effected by; 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 commitment, communication and organization, and individual factors such as personal characteristics and prior experiences (Almajed, Skinner, Peterson, & Winning, 2016; Richter & Paretto, 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.

2.3. Significance of the Project

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). 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: a) students' learning experiences and b) perceived skills to work in 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 at a bachelor level. 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 study student learning and improvement with regards to multidisciplinary teamwork using multiple data collection strategies, c) findings will be inspirational in exploring multidisciplinary teams 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, articles, 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 influence multidisciplinary teamwork in the context of the course. The research questions of the project are:

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

What are the perceptions and experiences of students about their learning in multidisciplinary teams in the context of the course 3BYX0P?

What are the perceptions and experiences of the teaching team about students' learning in multidisciplinary teams in the context of the course 3BYX0P?

What are the elements of multidisciplinary learning environment that foster student learning?

2. How does students' perceived skills to work in multidisciplinary teams change during the 3BYX0P – CBL Systems and Control course?

3.Method

3.1. Research Design

The “Deepening Multidisciplinary with Systems and Control” project uses qualitative and quantitative data to address its research questions. Table 1 presents the project alignment. Regarding the first 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 are identified out of qualitative data. In order to answer the second research question, the project adopted a convergent parallel design 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 (Creswell, 2012). The qualitative and the quantitative data will be collected and analyzed separately to arrive at complementary results (See Figure 1).

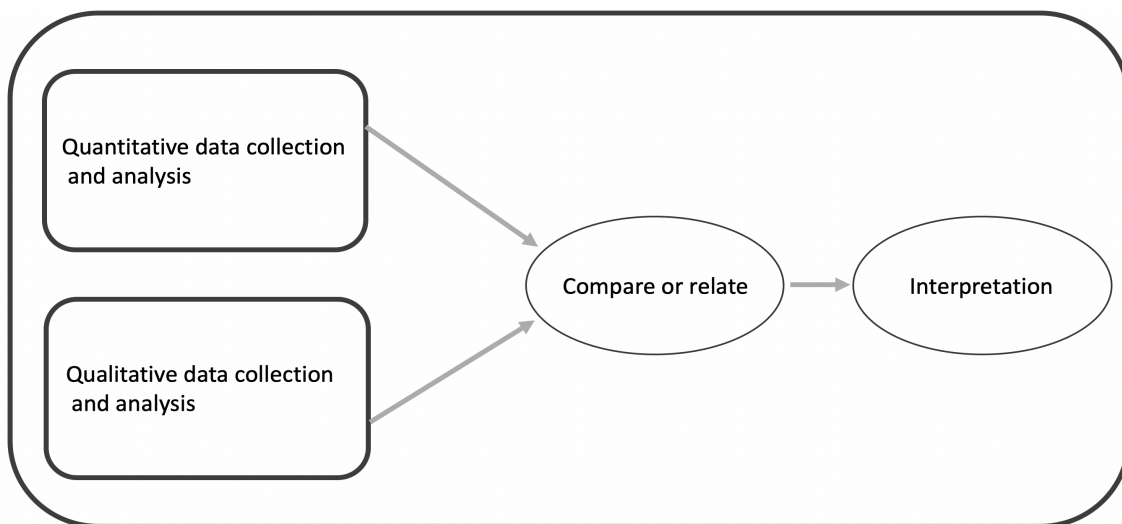


Figure 1. Convergent mixed-methods design (Creswell 2012, p. 541)

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?	Qualitative research	Perceptions and experiences of student learning	Student and teacher interviews, and students’ design artefacts	Qualitative data analysis
	Case study design	Elements that foster learning in multidisciplinary teams	Student and teacher interviews, student reflection reports and observations	
2. How does students’ perceived skills to work in multidisciplinary teams change during the 3BYX0P – CBL Systems and Control course?	Mixed-methods research	Perceived skills to work in multidisciplinary teams	Survey, student interviews, and observations	1a.Analyze side by side, then 1b.Compare results
	Convergent parallel design			2.Joint display for extremes Qualitative data analysis Data analysis in convergent parallel designs

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 and D2: cognitive interview result	
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-November, 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 (with the related work of a systematic literature review) 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) perceived skills to work in multidisciplinary teams, b) student learning in the course, and c) elements that influence multidisciplinary teamwork (See Table 1). The observation protocol (See Appendix F) is prepared to guide the investigation of multidisciplinary teamwork in its natural context. 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 the adaptation of an existing survey at the TU/e context before its implementation in the “3BYX0P-CBL Systems and Control” course during WP3. 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 second research question of the study 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 the 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 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 skills 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 and 2) conducting cognitive interviews with students as a form of laboratory 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” 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. Once this step is complete, we used the adapted survey for our pre-assessment in the context of the course.

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 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
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
At the end of course	Student artefacts	Design products, reflection reports	30 students taking the course

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 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.

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

	“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
Clarity	“clearly identify” to “identify” for Item 5

	“identify the type of knowledge and skills” to “identify the knowledge and skills” for item 5
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	“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
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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 be 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 working 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 engineering education, design of CBL environments and how students work 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 and 2) laboratory methods; cognitive interviews (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).

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.

6. References

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APPENDIX A Project Guide

the project

Addressed needs


- Exposing students to collaboration of knowledge and methods of **multiple disciplines**
- Limited evidence** on the nature and the learning benefits of multidisciplinary teamwork
- Explore how the **multidisciplinarity course setting** impacts student learning and improvement

Goal 



We aim to understand...

- students'** experiences and perceptions abt. **learning** in multidisciplinary teams
- the **potential elements** that contribute to effective multidisciplinary teamwork

Context 

The course: 3BYX0P CBL Systems and Control Project

- AP and ME students

Students


7 Applied Physics (AP) and 23 Mechanical Engineering (ME) students

Teams

Three of the teams will consist of 1 AP and 5 ME students, two teams will consist of 2 AP and 4 ME students

Collaboration

Continuous contact and exchange of information between student teams, the teachers and the researchers



Practical points

Frames

Challenge-based learning
Interdisciplinary learning
Multidisciplinary teams
Cross-disciplinary learning in teams

Research design

Mixed methods research;
concurrent collection of quantitative and qualitative data

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

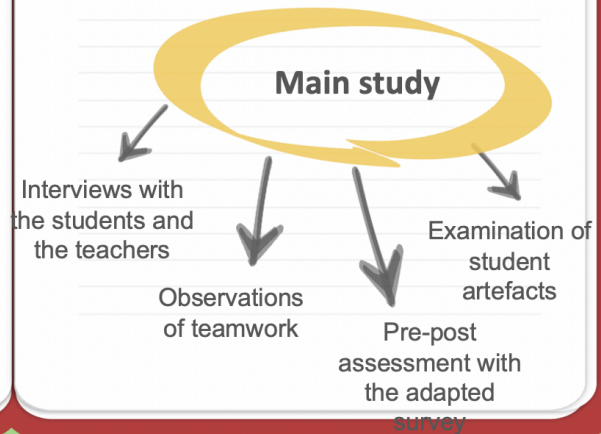
Attention to interdisciplinary coursework and benefits of multidisciplinary teams

Mind the two phases

Before the course starts



In the course context



APPENDIX B
Project Information for Students

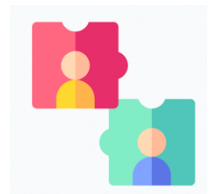
Deepening Multidisciplinarity with

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 6 th & in June	Last three weeks of the course	Four times through the semester
To be available in class and online		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:** Multidisciplinary 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

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?

3b. 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?

3c. 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?

3d. 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

Prompts for possible facilitators you experienced:

- 1.a.** The content of the challenge/project; *alignment between the challenge and the disciplines; AP and ME*
- 1.b.** The learning environment
- 1.c.** Teaching elements
- 1.d.** Team elements

Part-III

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

Part-I

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. Now please consider the students' progress through this course 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. Once again, please consider their progress through this course.

3.a. 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?

Prompts for possible facilitators you experienced:

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

1.b. The learning environment

1.c. Teaching elements

1.d. *Team elements*

Part-III

1. Describe any learning 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
the course*

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**

Site Observation Protocol for Taking Field Notes

Pre-Observation

I. BACKGROUND INFORMATION

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

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)
	<u>CONTEXT: The team</u> <ul style="list-style-type: none"> • Who are involved in the team? Describe the observable characteristics of the students. 	
	<u>ACTIVITY: The activity/task</u> <ul style="list-style-type: none"> • What is the topic/goal of the activity/task the students are working on? <p>The nature of multi-disciplinary learning in teams, note instances where the team members reflect the below three actions.</p>	

Time	Description of Events (Note the instances that address the research questions.)	Observer notes on the events/ codes (Note down emerging codes)
	a) <i>identification</i> b) <i>recognition</i> , c) <i>integration</i> ,	
	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:	

APPENDIX G
Multi-Disciplinary Team Learning 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

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.

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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