Up to the Challenge?

Fostering critical thinking through challenge-based learning

Thesis BSc

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Class of 2022

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Abstract

Challenge-based learning is one of the newer educational methods to instruct students. However, as it is still relatively new, there are multiple unknowns regarding the effects of challenge-based learning. At the University College Twente, first-year students work on a semester project in which the challenge-based learning (CBL) practices are employed. Moreover, external experts in the relevant fields are involved to support and help the students. This research investigated the impact of the external experts, focussing on the effect on the critical thinking activities (CTAs) of the students. Using recorded meetings, different CTAs were observed and coded to create a developmental chart over the semester. Students were asked to fill in two surveys, one in mid-terms and one at the end of the semester, to see what students noticed in their CTA development due to experts. Last, a focus group was organized where the participants were asked to elaborate on their experiences from collaborating with the experts. Although the students did not show an increase in CTAs during the meetings, the students did indicate that the experts helped develop their CTAs. Furthermore, the experts provided support in broadening the students' perspective. Future research could investigate the effects of CBL whilst considering the impact of interpersonal relations with the experts.

Keywords: Challenge-based learning, critical thinking, external experts

Table of Contents

Introduction

In the 1970s, educational systems were designed and implemented based on the needs of the world at that time. However, in the fifty years that have passed since, technology and education have developed at a high pace (Apple Education, n.d.; Robinson, 2007). With the advent of the internet and other technological developments, the need has arisen to educate students to navigate this new digitalised world (Robinson, 2007). As the world has changed in terms of globalization and intertwined economies (Chalkiadaki, 2018), educators had to adapt policies and educational practices at the beginning of the 21st century (Fredriksson, 2003). To prepare students for the emerging challenges, a new teaching philosophy has been explored: Challenge-Based Learning (Apple Education, n.d.; Nichols & Cator, 2008).

Challenge-Based Learning (CBL) is an educational philosophy introduced at the beginning of the millennium (Apple Education, n.d.; Giorgio & Brophy, 2001; Nichols & Cator, 2008). CBL allows students to explore outside their area of expertise through real-world interaction. For example, engineering students could work on a project and experience the legal side of engineering or the social impact of an engineering project. Students identify a problem and attempt to develop a solution to their defined problem (Chanin et al., 2018; Cheng, 2016; L. F. Johnson et al., 2009; Malmqvist et al., 2015). The CBL instructional approach emphasizes the students' ability to collaborate, with each other and others, while working on a real-world problem using a range of skills and knowledge (Gallagher & Savage, 2020).

Several researchers have set out to study the effects of CBL on students. The teaching style has been successfully implemented in several countries (Barry et al., 2008; Chanin et al., 2018; Eindhoven University, n.d.; Jezdimirovic Ranito, 2022; Ruijten-Dodoiu, 2022), providing researchers the opportunity to examine the impact of CBL on students. Several studies have been conducted in recent years, three of which will be discussed in more detail.

Leijon et al. (2021) examined papers published between 2009 and 2020 to identify patterns in research on CBL implementation in higher education. The paper reports that most studies are at a case-based level, while the impact of the CBL in higher education is under-researched. This means that the broader impact of CBL is not well-researched yet, mainly because of the limited scope of implementation in higher education institutes. The authors recommend further research on the impact of CBL in higher education, on student opinions of CBL, and evidence of improvement and learning.

Some research has been conducted on the effects of CBL on learning. L. Johnson and Brown (2011) examined the effects of CBL after the teaching style was implemented in the educational system in nineteen schools in the United States (17), Canada (1) and Australia (1). Among these schools were twelve schools that provide higher education. CBL is still practised in these schools today (L. Johnson & Brown, 2011; L. F. Johnson et al., 2009), showing that the teaching style was considered effective.

Among these schools, students and teachers found CBL to be highly effective and engaging, with 80% of students reporting that they felt their projects made a difference. In addition, 90% of teachers reported improved competencies in 21st century skills such as leadership, collaboration, and critical thinking. In general, both students and staff reported improvements in their own 21st century skills, with 90% of teachers stating that their 21st century skills had improved and 82% of students stating that their 21st century skills had improved. However, the researchers noted that more research is needed on the specific impact of CBL on students.

Caratozzolo and Membrillo-Hernández (2021) studied the effects of CBL on students' development during *I-week*, a week in which students have no classes for a week and participate in a CBL project at the university Tecnológico de Monterrey in Mexico. These projects were developed by lecturers with the help of experts from large businesses, industry, or social organizations. In these projects, the students collaborate with these experts in the field on their challenges to mitigate the problem in the challenge. Using a satisfaction survey, the researchers investigated the effects of the CBL teaching method on the students over the course of three years. Over 80% of the students were satisfied with the CBL teaching method. Student appreciated the evaluation methods, where both external stakeholders and internal university professors were assessors to the work presented. In addition, the teachers and experts were satisfied with the results and competencies that the students showed during the project work, with many stating that the students gained skills that they associated with critical thinking.

Other researchers have also pointed to the impact of CBL, noting positive influences on critical thinking, attitude, and collaboration (Barry et al., 2008; Chanin et al., 2018; Gallagher & Savage, 2020). In particular, Gallagher and Savage (2020) investigated the main finding of several CBL research studies in a literature review. In the literature review, only papers that were including CBL, were focussed on higher education, were English language journal articles or conference papers and were full peer reviewed were included in the review. In total, 95 articles were analysed in the study. Five additional papers were added in a second screening to create a total set of 100 papers being analysed. Of these 100 papers, several positive effects of

CBL are reported, especially in terms of teamwork, application of skills and understanding of knowledge (Conde et al., 2017; Gama et al., 2018; Kohn Rådberg et al., 2020; Lin & Chen, 2017).

This report focuses on the effects of CBL on critical thinking (CT), specifically the effect of the expert interactions on the students' critical thinking. It attempts to create an understanding of the effects that external expert interactions have on the critical thinking of students. Some studies have investigated the effect of CBL on critical thinking. For example, Okolie et al (2022) investigated which teaching approaches in higher education could improve the critical thinking skills acquired by students. Using interviews and a survey, they examined critical thinking teaching approaches in the Global South (Africa, Latin America, Oceania, and Asia). These interviews and surveys were conducted with the 55 participants that had volunteered in the research. Based on the interviews and survey, the researchers discovered that the teaching activities and courses that allow students to question existing beliefs and challenge them seem to influence the development of critical thinking. Problem-based learning is mentioned as a teaching style in which students can acquire critical thinking skills. As challenge-based learning has evolved from problem-based learning (Gallagher & Savage, 2020; L. F. Johnson et al., 2009; Lai, 2011; Leijon et al., 2021; Lin & Chen, 2017), similar results are expected to be found when investigating the effects of CBL on the students' critical thinking.

The presented research takes place as part of the semester two project in the undergraduate program Technology and Liberal Arts and Sciences (ATLAS) within the University College Twente. In this program, students participate in a semester project each semester, in which they are asked to solve problems and challenges in a multidisciplinary and transdisciplinary way. The semester two project of 2022 revolves around sustainable oceans. Students define a problem related to a technology in biotechnology, energy, or transportation. They then delve into the topic and write a short- and long-term sociotechnical scenario that is tested in a theatrical technology assessment (TTA) (Jezdimirovic Ranito, 2022). Students will focus in their project on problems from a multidisciplinary standpoint and address the technical difficulties and social/political implications to which students will write the scenario with their future prediction. Students are assigned two experts from different fields with whom they meet regularly to discuss ideas and gain insight into real-life scenarios in the field. In addition, the experts give students the opportunity to gain experience about current practices in the field and the technologies that are on the verge of broader application. This can be done through the meetings, materials that the experts provide to the students or during the guest lectures that the students get from the experts. Finally, the students will ask the experts questions regarding knowledge in the field and will engage in discussions with the experts in the meetings and will provide their ideas to be challenged and defend their point of view towards the experts. Additionally, the students can use the experts in a variety of ways: asking for feedback, teaching the experts something from the students' field to have a more in-depth discussion or helping them structure their thoughts. This research was part of a larger study that examined the impact of challenge-based learning on all stakeholders involved in the semester two project. It focused on the impact of CBL on students, faculty, and external experts. This study is focused on the second research question of the larger research and used it as the main research question.

The study presented aims to investigate the dynamics between CBL teaching practices and the impacts of external stakeholders on students' critical thinking activities. As described above, CBL practices have shown to have a positive impact on the students' skills growth. In addition, research indicates that engaging external stakeholders/experts can increase students' skill gain (Caratozzolo & Membrillo-Hernández, 2021; Gichohi, 2015; Sam & Dahles, 2017). It could therefore be expected that expert interactions also have a positive effect on the development of the students' critical thinking.

The main research question is:

What is the effect of expert interaction on the critical thinking activities of students in Challenge-Based Learning?

Based on this research question, two sub-questions were formulated to answer the main research question, which were:

1) *What is the effect of the expert interaction on critical thinking activities in the meetings?*
2) *What is the perception of students on the effects of expert interaction on their critical thinking activities?*

The hypotheses are that the experts will have a positive effect on the development of critical thinking activities (Gichohi, 2015; Sam & Dahles, 2017). It is also expected that the students will positively evaluate the interaction with stakeholders (Caratozzolo & Membrillo-Hernández, 2021).

Critical thinking is the main research variable measured in this study. Ahern et al (2012) explored whether critical thinking can be defined as a skill in a specific discipline or as a general skill. Based on several interviews and a literature review, the authors indicate that critical thinking is a process: the ability to use a theory and understand it beyond the abstraction of research but also the ability to use that theory to justify one's own statements. However, the definition of critical thinking in academic research is disputed and there are different interpretations when critical thinking is used in academic research (Cooper, 2016; Danczak et al., 2017; Facione, 1990; Guerra & Holgaard, 2016; Orozco, 2023 expected; Stowe & Cooper, 2017; Tiruneh et al., 2017).

Guerra and Holgaard (2016) argue that critical thinking is a collection of cognitive acts, with the aim of examining, revising assessing or judging theories, models and ideas based on arguments and evidence. Critical thinking is a continuous process where the models and theories are reviewed in the light of different perspectives and evidence, and the connection between these perspectives. Additionally, Danczack et al.(2017) identify critical thinking as the skills of identifying issues and arguments, recognising underlying assumptions, evaluating evidence or authority and drawing conclusions. Based on these sources in this study critical thinking is defined as the act of questioning, examining and/or judging something or someone.

The research variables were defined through a literature review to identify aspects of critical thinking used and operationalized in academic research. Several papers were analysed, and it was decided to group the various aspects into critical thinking activities (CTA). The majority of conceptualizations agree that critical thinking consists of a skill-based aspect and a dispositional aspect (Dwyer, 2017; Moore, 2013; Quinn et al., 2020). The CTAs defined are a reflection of the skill-based aspect for measurability. The CTAs that were defined are: assumption recognition (ASS), argumentation (ARG), evaluation (EVA), and decision making (DM). In the following paragraphs, the CTAs will be discussed in more depth. As mentioned above, the students must work with the experts and develop a scenario for their assigned technology. The CTAs chosen are based on the literature regarding critical thinking and the activities that the students take during the scenario building.

Students recognize, examine, and identify their assumptions as they collaborate with the external experts. The CTA involved in analysing the propositions within an argument is assumption recognition. Several researchers (Dwyer, 2017; Facione, 1990; Quinn et al., 2020; Tiruneh et al., 2017) that attempt to operationalize and conceptualize critical thinking, cite analysing the underlying premises (i.e. assumptions) within an argument as a critical thinking skill. As McPeck (2016) argues, the most dangerous assumptions are those that are "hidden", the assumptions of which one is unaware are more dangerous than the assumptions one appreciates. Therefore, it is important for students to be able to identify their assumptions in the semester project, as students are expected to write a sociotechnical scenario, in which they create a scenario for their technology for the coming decades. When writing such a scenario, it is important to identify and evaluate the assumptions used in the argument, because if they are wrong, the entire scenario may become invalid. Students are expected to carefully analyse their own viewpoints and arguments in relation to their assumptions through interaction with the experts, especially when students present their arguments to experts in the field. The experts have a wealth of knowledge in their field; therefore, they can help students better understand their assumptions and point out assumptions that are not entirely correct.

The CTA that involves the act of presenting propositions to another party with the aim of convincing the other party of one's conclusion is argumentation. This has been considered a critical thinking skill in several studies (Akbari et al., 2018; Dwyer, 2017; Jiménez-Aleixandre & Puig, 2012; Quinn et al., 2020). This skill involves presenting reasons as to why one has reached a particular conclusion, and why one should agree with the conclusion (Esudu, 2020; Facione, 1990; Lewiński & Mohammed, 2016; van Eemeren et al., 2015). Students create their scenario and support it with arguments and data to convince teachers and experts that their scenario is plausible in the future. Students are also expected to engage in discussions with their assigned experts. This further increases the need for arguments in the meetings as the experts need well-reasoned arguments to accept a conclusion drawn by the student groups.

Evaluation is the act of querying evidence for the argument and analysing the strength of the argument (El Soufi & See, 2019; Jiménez-Aleixandre & Puig, 2012; Lin & Chen, 2017). Students participating in evaluation examine the claims made in the arguments. The ability to evaluate the strength of arguments and weigh them against each other has been repeatedly considered a critical thinking skill in research (Guerra & Holgaard, 2016; Quinn et al., 2020). Students are expected to weigh the opinions of assigned experts and university tutors using the various aspects offered by both sides: one side has more knowledge of the content as an expert in their field, the other side offers different insights and keeps the academic performance on the required level. Students will examine the experts' and tutors' statements with the knowledge they have gained from their own research, reviewing and weighing the strength and underlying premises of the argument.(Guerra & Holgaard, 2016).

Decision making can be defined as the act of weighing different options and considering the consequences before deciding on a course of action (Bradley & Price, 2021; Guerra & Holgaard, 2016; Lee et al., 2017; McPeck, 2016; Rababa & Al-Rawashdeh, 2021). Students will receive all the information from the tutors and experts, and after discussing with the experts, tutors, and peers, students must decide which direction that they want to take. For example, this may apply to the socio-technical scenario. Students must make several decisions regarding their technology and the direction the technology will take in the future (Jezdimirovic Ranito, 2022). Since these decisions will affect the rest of the scenario, students must choose the path that seems most logical to them for the technology to continue. Students must weigh the data found in the research and expert meetings to decide which path to take with the technology.

Method

It should be noted that over the course of this study, an additional research question was formulated. During the research process and intermediate data analysis, the results of the first research question did not show development in critical thinking in the students after the data analysis. The meeting coding showed that there was hardly any critical thinking occurring in the meetings and that there was no apparent increase. However, the survey did show some critical thinking development in the students (self-reported). To explore this apparent difference in results, it was decided to conduct a focus group with the team leaders to explore the impact of the interactions with the experts more in-depth, as the students indicated that the experts helped them develop critical thinking without this being apparent in the meetings. The sub-research question formed for the focus group was: *What is the perception of the team leaders regarding the influence of experts on their and their group's critical thinking activities?* From this point onwards, the third research question will be discussed alongside the other research questions. The procedure section will further elaborate on the timeline of the study and the inclusion of the third research question.

Participants

The participants were first-year students in the Technology and Liberal Arts and Sciences bachelor's programme at the University College Twente (*n* = 27, ten female). This group was selected because they participated in the semester two project, using the teaching methods of challenge-based learning. The students were divided into five project groups consisting of five or six members. Ethical approval was obtained from the ethics committee of the Faculty ITC of the University of Twente. Ethical concerns were raised regarding data storage, which were addressed by setting up an encrypted folder in the University of Twente's OneDrive, which allowed for sufficiently secure storage of materials. Participants signed an informed consent form regarding their participation in the study. Students were not informed about the CTAs under study so as not to influence students in their meetings. Students knew they were participating in a study examining the effects of CBL, but they did not know the specific variables being studied and were later informed verbally.

In addition, the facilitated focus group consisted of six students (three females). All participants were either team leaders of the project group or active members in the groups selected based on the judgement of the semester teachers.

To protect participant privacy, survey responses were not linked to individuals. Instead, respondents were each given a randomized identification key to the responses that could be used to distinguish responses. Although the recordings were not anonymous, students were referred to as “Student 1,2 etc” and the experts as “Expert 1, 2” in the transcripts so that identification was not possible in the transcripts.

Materials

Expert meeting recordings and coding methods

To investigate whether there was an effect of the experts in the meetings, the meetings with the experts were recorded. Firstly, students’ laptops were used to record their meetings with experts using Microsoft Teams. This allowed for secure sharing of the recordings and storage on OneDrive. The students were informed in person about how to record the meetings in Teams (by clicking the record button in the meeting). Secondly, the recordings were transcribed using the software Amberscript (Amberscript.com), a transcription software used and offered by the University of Twente. Thirdly, coding was performed using Microsoft Word. This method of coding was considered as the most efficient and data secure. The coding scheme itself can be found in Appendix A. This consists of a table where the total amount of CTAs displays is logged and counted. The descriptions of the CTAs were provided to the coders and the coders were asked to count the number of CTAs in accordance with the definitions provided.

Surveys

To answer the question regarding the perception of the students regarding the effects of CBL on their critical thinking, two surveys were created. For this, a software called Maptionnaire was used, a software with a license from the University of Twente that allowed data protection and storage of results. The first survey (to be called mid-term survey) consisted of two parts: the first part requested the students to reflect on their learning process from the stakeholders, using the following questions regarding the impact of the expert on the team's thinking: "Think back about the encounters you had up until now and identify a situation in which the expert, in your view, had a significant impact on your team's thinking.

1. What was the situation? (who, what, where, how?)

2. In what way did the situation matter, or why was it significant?

3. How did the situation further affect the course of your group's project? "

These questions were asked as part of the larger research that this research is part of, but also allowed the researchers to identify whether the students themselves recognized that something changed in their critical thinking, if that had happened.

The second part consisted of a 5-point Likert-scale ranging from "Fully Disagree" to "Fully Agree". The statements to which the students responded were:

(1) The expert supported my team in recognizing and addressing assumptions.

(2) The expert supported my team in building arguments using literature, logic, and base knowledge.

(3) The expert supported my team in evaluating claims; discussing ideas to see the arguments in favour and against these ideas.

(4) The expert supported my team in making decisions based on ideas discussed.

The mid-term survey can be found in Appendix B.

A second survey (to be called end-term survey) was sent out as well. This survey was similarly split in two parts. The first part focussed on the student's reflection on the semester project. This was formulated as:

"During semester 2 project you had opportunity to work with two external experts, who were available to provide perspectives on the topics you researched. Now that project is completed, and cooperation with them is completed, we would like to know what you gained with their collaboration in project. Think of the skills and perceptions that you developed through this period by having discussions/meetings with the experts. This could include better organization of thoughts, or widening your perspective to make more comprehensive analysis, critical thinking, better teamwork, or something entirely different! How did the experts help you gain those skills/perspectives?"

The question was meant to be focussing on the other research questions in the overarching research that this paper is part of, but it did allow students to discuss their skills, and could have led to students bringing up critical thinking on their own. The second part of the survey was the same as the first survey, asking the students to respond to the same four question using a 5-point Likert-scale. The end-term survey can be found in Appendix C. The second survey was sent to measure the potential change of the student opinion on the expert interactions and to counter the effect of rosy retrospection (Zurbriggen et al., 2021). Additionally, the two surveys allowed for comparison on the student opinion regarding their experts at two separate times.

Focus group with team leaders

To answer the third sub-research question, which focussed on the group leader perception on the expert interactions. a focus group was held and was recorded in Microsoft Teams. Amberscript was used to transcribe the recording for analysis. The focus group was held in the afternoon on the 22nd of June 2022 and was held online for recording purposes and a COVID-19 infection of the interviewer. The following questions were asked to the students: What do you think that the experts brough the most to the semester project? Are two experts the right number of people, or would a different number of experts be better? Did the experts help you develop any critical thinking activities? What did the experts do that was most valuable to you in the scope of the project?

There were questions asked that had to do with the overarching research, which will not be used in this study, meaning that the following questions will be focussed on in the results section: What do you think that the experts brough the most to the semester project? Did the experts help you develop any critical thinking activities? What did the experts do that was most valuable to you in the scope of the project?

Procedure

At the semester start, the students were instructed to record the meetings on their laptops. They were shown the recording button in Teams and were shown where they could upload the meeting recordings. The students continuously recorded the meetings they had with their experts and sent them to the researchers. The students received an email halfway through the semester with the mid-term survey. They were asked to fill in the survey (link provided in the email). Though in-person and email reminders, the students were reminded to fill in the survey. During this time, the meetings were moved to the secure storage, transcribed, and coded. It was planned to link the CTA occurrences to the expert interactions. However, in the first meetings a trend was discovered: every interaction within the meeting was an interaction with the stakeholder and the students rarely displayed CTAs. It was therefore decided to discontinue the process of including the transaction part of the codings. Two co-coders were introduced to the CTAs and the definitions to ensure that the coders understood the coding scheme and the definitions. The co-coders worked on six recordings. At the end of the semester, the end-term survey was sent over email to the students with the request to fill it in. When the data analysis on the meeting codings and the surveys had begun, it was quickly seen that there was little CTA development in the meetings themselves. Therefore, a focus group was hosted three weeks after to get the team leader's view on the interactions with the experts. Here, the students were asked what their opinion was on the expert interaction, what skills the experts have given them and how the experts, in their opinion, influenced their critical thinking.

Data Analysis

Expert impact on meetings

The first meetings of the teams with their experts were meetings where the teams were able to get to know each other. Therefore, these meetings have been omitted from the data analysis, leaving a total of thirty meetings for the data analysis and coding. Using Excel, the frequencies of the CTAs were calculated in all the meetings. No meetings were excluded. The averages, standard deviation and the frequencies over time were calculated and plotted (See Figure 1) to see whether there was an increase in the CTA count per meeting over the course of the semester due to expert interaction. To calculate the total frequencies and the average frequencies of the CTA in general, the CTAs were plotted for the total amount of meetings and the number of meetings per group. Furthermore, the number of CTAs per group were plotted as well as the number of CTAs per group per expert meeting. Additionally, number of CTAs observed was plotted against time to measure the development of CTAs occurrence in the expert meetings. Last, the amount of each individual CTA was plotted over time to investigate a change in the amount of observed number of CTAs occurring in the expert meetings. This data would allow the first sub-question to be answered.

Student perception on experts

The results from the survey were imported and were compared per group. The responses were grouped by the students' project groups and plotted per CTA and per group. This means that there was one graph depicting what each group had answered on all four CTAs on the 5-point Likert scale and one graph showing what each group had responded to the question regarding one specific CTA. This allowed for general comparison of the perceived contribution from the experts to CTA development as well as comparing which groups were agreeing on the statement regarding a specific CTA compared to the other groups This data would allow the second sub-question to be answered.

Team leader perception on experts

The focus group recording was recorded and transcribed. The transcription was read and explored by highlighting the statement that the student made regarding the experts and their interactions with them. These statements were then ordered in positive and negative utterings, and the content of the statement: Perception, structure of thoughts, experts, and CTA. These colour codes helped the researcher get an overview of the general opinion from the team leaders on the interaction with the experts. There was no specific coding scheme, as the single focus group allowed for open coding, which was then merged into axial coding. The focus group results will be outlined according to the findings following from the free coding. Based on the questions outlined in the method section and the data gathered, the utterings from the students have been categorized and will be discussed along these categories.

Results

Effect of the experts in the meetings

A total of thirty meetings were recorded and analysed. In these meetings, a total of 106 CTAs were coded by the three coders (Cohen's kappa =*.42*). In Table 1, the results of the coding of the student recordings are depicted. On average, 3.53 (*SD*= 1.8) CTAs occurred per meeting, where argumentation occurred the most times. Groups one and two had the least number of meetings, three and two, respectively. No assumption recognition was identified in 50% of the meetings, 23% of meetings showing no argumentation, 53% having no evaluation shown and in 56% of the meetings, the students did not show decision making.

The average number of CTAs shown in the meetings varies from group to group. The average is between 3.00 and 5.50 per meeting. Group 2, with two meetings, showed the highest averages in general compared to the other groups. Group 5 had the highest number of meetings, although the group has displayed the average amount of CTAs.

Figure 1 displays the CTAs shown in meetings over time. The sum line depicts the sum of the total CTAs shown in a single meeting, whereas the bars show the number of specific CTAs shown per meeting. The sum line of the CTAs displayed per meeting is going up slightly for groups 1, 2 and 3, whereas the line moves more randomly for groups 4 and 5.

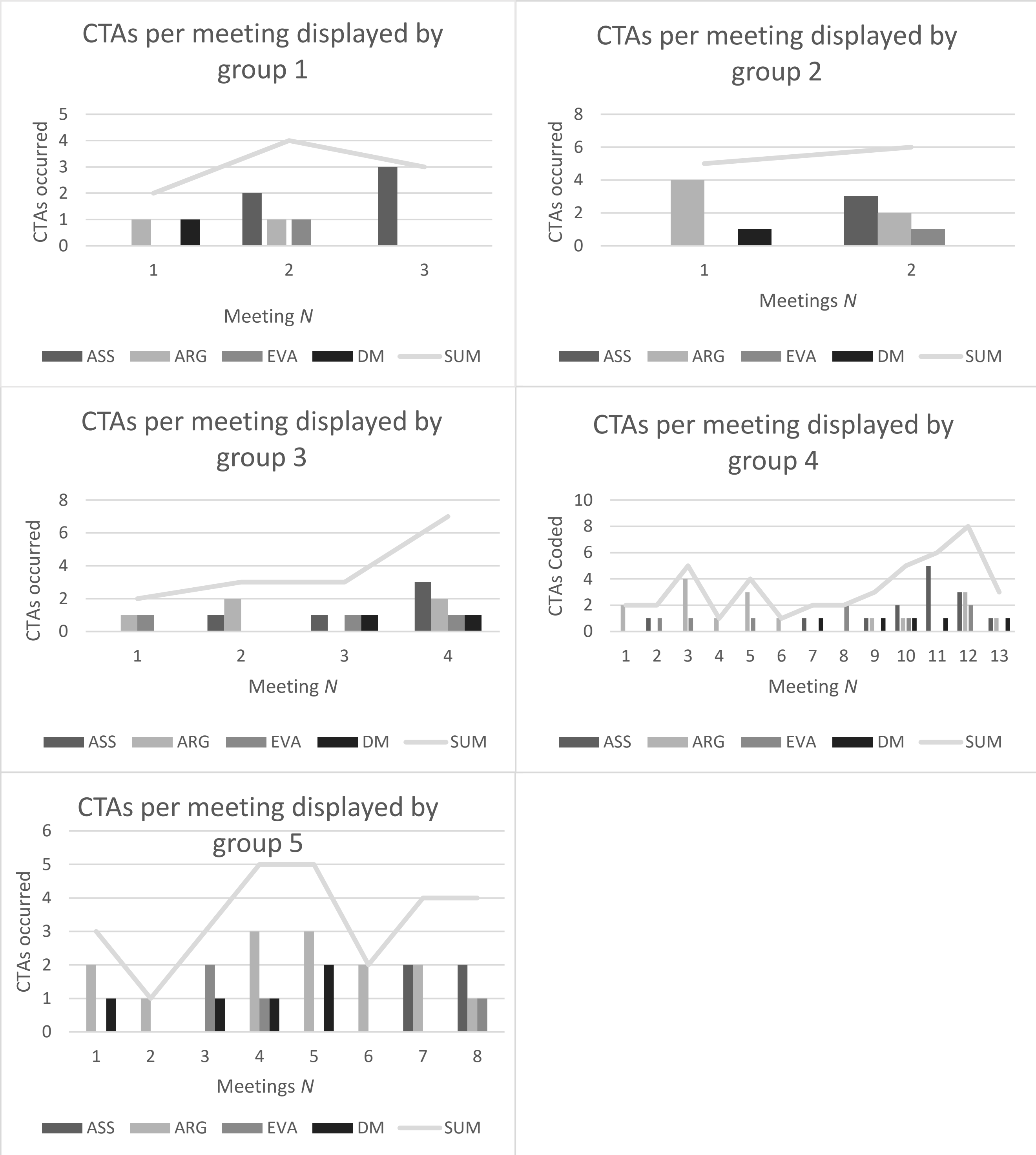
Table 1

Overview of CTAs counted per meeting per group.

Group	ASS	ARG	EVA	DM	SUM
1	0	1	0	1	2
	2	1	1	0	4
	3	0	0	0	3
Mean	1.67	.67	.33	.33	3.00
SD	1.53	.58	.58	.58	1.00
2	0	4	0	1	5
	3	2	1	0	6
Mean	1.5	3.00	.50	.50	5.50
SD	2.12	1.41	.71	.71	.71
3	1	2	0	0	3
	0	1	1	0	2
	1	0	1	1	3
	3	2	1	1	7
Mean	1.25	1.25	.75	.5	3.75
SD	1.26	.96	.5	.58	4.92
4	0	2	0	0	2
	1	0	1	0	2
	0	4	1	0	5
	0	1	0	0	1
	0	0	2	0	2
	2	1	1	1	5
	3	3	2	0	8
	0	3	1	0	4
	0	1	0	0	1
	1	0	0	1	2
	1	1	0	1	3
	5	0	0	1	6
	1	1	0	1	3
Mean	1.08	1.31	.62	.38	3.38
SD	1.50	1.32	.7	.51	4.42
5	0	3	1	1	5
	0	1	0	0	1
	0	2	0	0	2
	2	1	1	0	4
	0	2	0	1	3
	0	0	2	1	3
	0	3	0	2	5
	2	2	0	0	4
Mean	.50	1.75	.50	.63	3.38
SD	.93	1.04	.76	.74	1.98
Total	31	44	17	14	106
Mean	1.03	1.47	.57	.47	3.53
SD	1.33	1.20	.68	.57	3.22

Figure 1

CTAs displayed per group per meeting.



Perception of students on the use of experts

There was a total of sixteen responses (response rate = 59%) to the midterm survey. In Table 2, the results of the mid-term survey questions are displayed. On average, the students rated the ability of the experts to help the student develop the CTAs for evaluation at 3.70 (*SD = .87*), for assumption recognition 3.80 (*SD = 1.05*), for 3.90 (*SD = 1.02*) on decision making and a 4.10 (*SD = .96*) for argumentation on the 5-point Likert scale.

Additionally, the students mentioned that the experts had an influence on broadening the students' perspective. Ten students mentioned that the experts had helped in broadening their perspective during their interactions. For example, one student recalled the interaction as "*The expert started talking about market shares […] that widened the scope of the project for me.*" Another student mentioned the fact that they received more knowledge and insight in the situation: "*This may be obvious, since we are being educated in the Netherlands and therefore the group may lack some international perspective. […], through our discussions with the experts, we were able to get a better perspective on the ways in which ports operate in different continents.*"

In the end-term survey, a total of fifteen students responded to the survey (response rate[1] = 68%) the students answer regarding the help of the experts were the following: The students answered to question regarding the ability of the experts to help them recognise assumptions with a 3.90 (*SD = .70*), argumentation with a 4.10 (*SD = 1.00*), evaluation with a 3.80 (*SD = 1.00*) and decision making with a 3.40 (*SD = 1.20*).

The reflection question in the survey yielded the same response rate. There were two students who looked negatively on the experts, where the students pointed out that they did not learn skills or develop skills from the experts. Thirteen students answered that they did learn some skills from the experts. Within these thirteen responses, the students indicated that the experts had broadened their perspective eleven times. One student puts it like this: "*The discussions/meetings with the experts helped with widening my perspective. Their knowledge expanded mine.*" Other students specifically highlighted that the discussions and meeting with the experts helped them expand their perspective and think about the project differently. Additionally, a student pointed out that the meetings helped their group take a step back from what they were working on and look at the problem from a different, and more distant perspective.

[1] Due to students dropping out of the program during the semester, the response rates are different between the surveys.

The students pointed out three more skills that they learned. On six occurrences, the students highlight the gain of critical thinking skills through their experts. "*I think the experts helped us to some extent to think critically. The main point that comes to my mind is that they were really careful regarding giving questions, saying their opinion and making assumptions.*" One student also highlights: "*Critically thinking about multiple different perspectives and being validated on the process we were undertaking [by the experts]*.". Additionally, three students mentioned that the expert contact improved their organization of thought, either actively or passively. "*We needed to make an agenda before each meeting with the experts and think about the questions we would ask. This way the experts stimulated us passively to organize out thoughts.*".

Table 2

Results of the mid-term and end-term survey regarding the development of CTAs on a 5-point Likert scale.

	Mid-term survey				End-term survey			
Group	ASS	ARG	EVA	DM	ASS	ARG	EVA	DM
1	4	4	4	5	4	5	2	5
	2	4	2	4	2	3	4	4
	5	5	5	5	3	5	4	2
	5	5	4	4	4	3	4	4
					5	5	5	5
Mean	4	4.5	3.75	4.5	3.60	4.20	3.80	4.00
SD	1.41	.58	1.26	.58	1.10	1.10	1.10	1.20
2	2	4	4	2	4	4	4	4
	4	5	5	5	4	3	5	2
	4	4	4	4	4	5	4	4
	4	4	4	4	4	3	4	4
Mean	3.5	4.25	4.25	3.75	4.00	3.80	4.30	3.50
SD	1.00	.50	.50	1.26	.00	1.00	.50	1.00
3	2	1	2	4	4	2	2	4
Mean	2	1	2	4	4.00	2.00	2.00	4.00
SD	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4	4	5	4	2	4	5	4	3
	5	5	4	3	5	5	5	3
	5	4	3	5	4	5	4	4
	4	5	4	4				
	4	4	3	4				
Mean	4.40	4.60	3.60	3.60	4.30	5.00	4.30	3.30
SD	1.26	.58	.50	1.26	.60	.00	.60	.60
5	4	4	4	3	4	4	2	1
	3	3	3	4	4	4	4	2
Mean	3.50	3.50	3.50	3.50	4.00	4.00	3.00	1.50
SD	.71	.71	.71	.71	.00	.00	1.40	.70
Total								
Mean	3.80	4.10	3.70	3.90	3.90	4.10	3.80	3.40
SD	1.05	1.02	.87	.96	.70	1.00	1.00	1.20

Perception of student team leaders on the impact of the experts

Student team leaders believed a major ability contribution of the experts was their ability to provide different perspective, or to broaden the students' perspective was pointed out by the team leaders to be a major contribution of the experts. As one student puts it: "*having multiple people because you will always benefit from multiple perspectives*". Additionally, the students pointed out that there were different benefits to different experts: "[*Expert 1] was really well-spoken and knew everything about shipping [...] [Expert 2] was maybe a bit less aware of the ins and outs, but would be more likely to talk about different topics [that were relevant]"*(Two other students expressing agreement).

In contrast, difficulties were also brought up by some groups as the experts did not have specific knowledge on the subject that the students were working on. Two students pointed out that they had experts that were not used to/had knowledge on the technology that the group was working on, becoming less useful to the student groups over the course of the semester. Students from two separate groups mentioned this experience. A solution one student posted is to have one expert in the domain assigned to you and have one expert to spar with for more structural conversations regarding the deliverables.

Besides broadening and providing different perspectives, one student mentioned that the experts were a soundboard "*to kind of share your idea with and they know enough to really respond to that and give suggestions*." (Three students expressed agreement). One student further mentioned the possible influence of the experts' character as a factor for fruitful collaboration.

When the students were asked what the experts had contributed to their critical thinking skills, students reported several observations regarding their interactions with the experts in the meetings and contact in general with the experts. The students reported that the experts did help them develop their critical thinking skills (Three students mentioned parts of critical thinking being helped). However, this came with the note that the students were not certain that the development would have happened without the experts as well (two students in agreement). The students do argue that in their view the expert interactions have accelerated their critical thinking development (all students expressed agreement).

Students pointed out that the experts did help the students in their decision making by suggesting courses of action and helping the students focus on what is more and less important. "*I really appreciated was the influence that they had on how we change the scope of our project* *and the decision we made about what we would include, what we wouldn't include, and what is really vital to complete this project"* (one student expressing agreement). Additionally, the students appreciated the ability of the experts to help the students organize their thoughts, as "*it is very easy to get lost in ideas and thoughts and theories."(*Four students expressed agreement). In addition, the experts were a useful source of knowledge. The experts have the knowledge of the fields the students were working in and "*they are able to explain concepts which you could not really find online, because most of the stuff is too specific for the general public […] that is too commonly known in the industry."*(Four students expressed agreement).

Besides active stimulation, the students indicated that the expert interactions helped them to develop critical thinking. Especially regarding argumentation and assumption recognition, the expert meetings stimulated the students to carefully assess their assumptions and argumentation. One student specified the situation for them: "*[…] just by the act of presenting your work to someone who is very knowledgeable about it, you already begin to filter it differently.*" (one student expresses agreement) Another student added to this: "*Since you have to explain it to someone else, you really have to think about why you do it in your argument."* (One other students expressed agreement)

As a final note, one student pointed out that it takes time to get used to the experts and how to get the optimal results from collaborating with their expert. The student stated that their team was searching how to make the most use of the experts. According to the student, this improved over the course of the semester, but the team was trying to figure out how to get the most from the expert interactions in the beginning (Three students expressed agreement). Additionally, the students mentioned that they had the realization that the more you know about a subject, the more difficult it is to formulate an opinion regarding matters in the subject, as you are aware that there are many perspectives and sides in each situation.

Discussion

This study attempted to investigate the effects of challenge-based learning teaching practices on the critical thinking of students. This was supported by the main research question and sub-research questions: *what is the effect of expert interaction on the critical thinking activities of students in challenge-based learning?*

What is the effect of the expert interaction on critical thinking activities in the meetings?

What is the perception of students on the effects of expert interaction on their critical thinking activities?

What is the perception of the team leaders regarding the influence of experts on their and their group's critical thinking activities?

In the meetings themselves, the students did not show an increase in display of critical thinking activities. The frequencies of the CTAs displayed did not show a significant increase and Cohen's Kappa was too low (= *.42*) to draw significant conclusions from the coding. Cohen's Kappa value can be explained by the difference in coders. Despite the student coders' introduction and explanations regarding the different CTAs, the coders sometimes expressed that they were struggling with specifically coding a statement in one of the CTAs. The nuances between the different CTAs proved difficult to understand for the additional coders and this can explain the discrepancies between the coders.

Besides Cohen's Kappa , no conclusion can be drawn based on the CTAs displayed in the meetings. With a total average of 3.5 CTAs displayed per meeting, the number of CTAs displayed is low for the number of students and different types of CTAs that can occur in the meetings. This low amount can be explained by the content of the meetings. It was noticed that in most meetings, the students' questions contained mostly content-related questions. The students mostly used the experts for knowledge gathering, something that was confirmed in the survey and focus group as well. It is therefore hard to draw any conclusions regarding the development of critical thinking through the expert meetings from the meetings alone.

Regarding the student opinion on the experts, the surveys have shown that the students do appreciate the expert interaction and that the students receive numerous benefits from collaborating with the experts. The students pointed out that the experts are beneficial for the students, as they provide knowledge and materials for the students to study and consider in their semester project. Students received materials like papers, but also received presentations with knowledge that the experts had given. The student opinion on whether the experts helped them with developing critical thinking skills is mixed. It seems that group who had more interaction with their experts have a more positive opinion on the influence of the experts on the CTAs.

In addition to gaining knowledge from the experts, the students mentioned that the experts help them structure their thoughts and help them view the problem from different perspectives and angles. The students mention that the experts provide a sparring partner that allows the students to bounce of idea’s and to provide a grander view about the challenge. The students gained the understanding that the situation that they work on is more complex and encompasses more disciplines, such as legislation. The evidence from the focus group and survey responses shows that the expert interactions, as viewed by the students, do provide multiple benefits for the students, and could potentially help development of critical thinking.

The team leaders of the groups, who had the overview of the group, were similarly positive regarding the expert interactions. The team leaders pointed out that the expert could potentially have accelerated their critical thinking development, as it is hard to state what would have happened if no expert interaction had taken place in the project. When asked however, the students did point out instances where they feel that the experts helped them develop critical thinking and their interactions with the experts have contributed to a development in critical thinking.

Interestingly, the students in the focus group did highlight the passive effect of the expert interactions in the project. The students felt that by presenting to and collaborating with experts in the field, they inherently were thinking deeper and more critically about the statements, assumptions, and decisions that they make. If this is an effect originating from solely interacting with the students, the act of introducing expert interactions in projects and courses could potentially introduce the concept of passive development of critical thinking development in students, which would be in line with the model of challenge-based learning: In the real-world interactions, the students will have to present to knowledgeable stakeholders as well. The skill that the students learned will be useful for them in the future and presents an interesting result for this study.

Secondly, the focus group added onto the survey results by confirming that the experts are a help in widening one's perspectives. The students reconfirmed that the interaction with the experts allowed them to gain different perspectives on the challenge and to take a step back to look at the challenge from a different perspective.

However, there is a difference between the experts: the students that worked the most with their experts (i.e., had the most meetings), reported that the expert was the most helpful to them on all fronts: knowledge, perspective gain and development of critical thinking. The character and field of the expert were mentioned to be an influence in this. The character and the interpersonal relationship between the experts and the students could influence the ability of the students to learn from the experts. It is a direction for future research to investigate the effect of the inter-personal relationships between the students and the experts on the students' learning opportunities. Research already has been done to student-teacher relationships (Martin & Collie, 2019), but little research to the effect of external experts has been found.

It is natural in a study that there are limitations. One such limitation of this study is the limited sample size and the nature of the program that this study occurred in. The students in the first year of the ATLAS programme are honours students at the University of Twente. As the sample size is well below forty, it is recommended that to study the impact of challenge-based learning is implemented in settings that allow for easier up-scaling of the sample groups Due to the unique nature of the program, implications of this study are hard to project on the general student body. It is recommended that future research not only upscales the sample group, but also implements the CBL teaching practices in bigger studies, e.g., mechanical engineering, to investigate the effects of CBL on students in a different discipline and in a program where the entry requirements and teaching environment are vastly different compared to a university college.

A different limitation was the clarity of the coding scheme. Despite efforts to give the coders an understanding of the coding scheme and the different critical thinking activities, the low value of Cronbach's' alpha indicates that the coding scheme was not clear enough to provide for consistent coding. Future research should focus on providing a clearer coding scheme for the coders, as the definitions of critical thinking are varying (Hakim & Talib, 2018). It is recommended for future research to build upon a test coding where the coders are more trained regarding the critical thinking activities coding. This could ensure a higher similarity in coding and more solid results.

Conclusion

This research aimed to explore the gap in knowledge regarding the development of critical thinking through expert interaction in challenge-based learning systems. The introduction presented three sub-research questions, which will be answered to answer the main research question:

(1) What is the effect of the expert interaction on critical thinking activities in the meetings?

The meeting recordings and coding did not provide sufficient evidence to make any conclusions regarding this research question, as the results show that there is not enough data to reach a conclusion regarding critical thinking activities in meetings.

(2) What is the perception of students on the effects of expert interaction on their critical thinking activities?

The students reported that the expert did help develop their critical thinking. Overall, the students reported expert interaction being helpful in developing the respective CTAs. Additionally, the students highlight that the expert interaction helps the students gain a wider perspective on the challenge and allows the students to work on the challenge with a deeper understanding of the different requirements. Last, the experts are a source of in-field knowledge for the students. The students gained knowledge from the experts that is hard to find or faster to gain through an expert.

(3) What is the perception of the team leaders regarding the influence of the experts on their and their group's critical thinking activities?

The team leaders indicated that depending on the perceived usefulness, the experts were positively influencing the development of the CTAs. Although it cannot be ruled out that the students would develop these skills on their own, the students seemed to agree that the experts did accelerate the development process. Additionally, the team leaders agreed that the experts helped broaden their perspective and had a role in passively influencing the students to develop their critical thinking.

Using the answers to the three sub-questions, the main research question can be answered: *What is the effect of expert interaction on the critical thinking activities of students in Challenge-Based Learning?*

Students reported benefits from meeting with the expert pairs and the expert interactions. They stated that the expert accelerated the development of their critical thinking, but that this depended on the use of the expert in the groups. Overall, it is hard to state that the expert interaction could have a positive effect on the development of critical thinking activities in the students. However, there are signs that the expert interactions have a positive effect on the students. Additionally, the effects of experts on the ability of students to view problems from multiple perspectives and the ability of the experts to passively influence the critical thinking of students are conclusions that can be drawn from this study.

Acknowledgements

First, I would like to thank my supervisors, dr. Jovana Jezdimirovic Ranito and dr. Pascal Wilhelm for their continued support over the past year and their guidance during my thesis time and my time in ATLAS. Thank you as well for the many meetings, in which we could always discuss the relevant topic, even if the progress was not too well, and for the occasional drifts off topic. I highly enjoyed working with the both of you.

Second, I would like to thank dr. Ardion Beldad for being my academic advisor over the last three years and providing guidance when needed, even if it was a little chat in the hallway for a quick ordering of thoughts.

Third, I would like to thank my friends and family for their continued support, distractions and making sure that there was also a life besides studies and working. It was a fun time and the many hours wasted going out or relaxing were exactly what I needed sometimes.

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Tables and Ffigures

Table 1

Overview of CTAs counted per meeting per group.

Group	ASS	ARG	EVA	DM	SUM
1	0	1	0	1	2
	2	1	1	0	4
	3	0	0	0	3
Mean	1.67	.67	.33	.33	3.00
SD	1.53	.58	.58	.58	1.00
2	0	4	0	1	5
	3	2	1	0	6
Mean	1.5	3.00	.50	.50	5.50
SD	2.12	1.41	.71	.71	.71
3	1	2	0	0	3
	0	1	1	0	2
	1	0	1	1	3
	3	2	1	1	7
Mean	1.25	1.25	.75	.5	3.75
SD	1.26	.96	.5	.58	4.92
4	0	2	0	0	2
	1	0	1	0	2
	0	4	1	0	5
	0	1	0	0	1
	0	0	2	0	2
	2	1	1	1	5
	3	3	2	0	8
	0	3	1	0	4
	0	1	0	0	1
	1	0	0	1	2
	1	1	0	1	3
	5	0	0	1	6
	1	1	0	1	3
Mean	1.08	1.31	.62	.38	3.38
SD	1.50	1.32	.7	.51	4.42
5	0	3	1	1	5
	0	1	0	0	1
	0	2	0	0	2
	2	1	1	0	4
	0	2	0	1	3
	0	0	2	1	3
	0	3	0	2	5
	2	2	0	0	4
Mean	.50	1.75	.50	.63	3.38
SD	.93	1.04	.76	.74	1.98
Total	31	44	17	14	106
Mean	1.03	1.47	.57	.47	3.53
SD	1.33	1.20	.68	.57	3.22

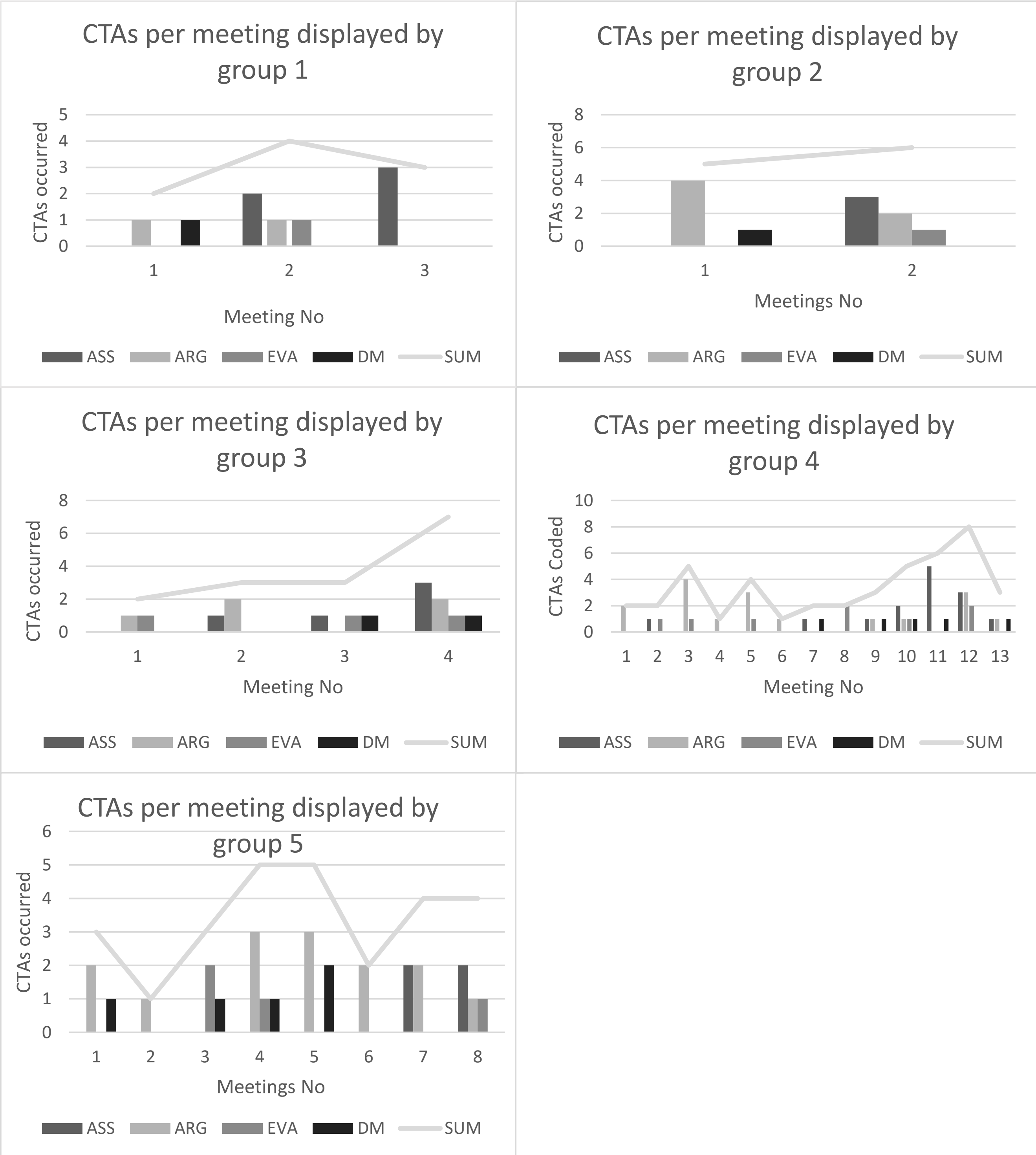
Table 2

Results of the mid-term and end-term survey regarding the development of CTAs on a 5-point Likert scale.

	Mid-term survey				End-term survey			
Group	ASS	ARG	EVA	DM	ASS	ARG	EVA	DM
1	4	4	4	5	4	5	2	5
	2	4	2	4	2	3	4	4
	5	5	5	5	3	5	4	2
	5	5	4	4	4	3	4	4
					5	5	5	5
Mean	4	4.5	3.75	4.5	3.60	4.20	3.80	4.00
SD	1.41	.58	1.26	.58	1.10	1.10	1.10	1.20
2	2	4	4	2	4	4	4	4
	4	5	5	5	4	3	5	2
	4	4	4	4	4	5	4	4
	4	4	4	4	4	3	4	4
Mean	3.5	4.25	4.25	3.75	4.00	3.80	4.30	3.50
SD	1.00	.50	.50	1.26	.00	1.00	.50	1.00
3	2	1	2	4	4	2	2	4
Mean	2	1	2	4	4.00	2.00	2.00	4.00
SD	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4	4	5	4	2	4	5	4	3
	5	5	4	3	5	5	5	3
	5	4	3	5	4	5	4	4
	4	5	4	4				
	4	4	3	4				
Mean	4.40	4.60	3.60	3.60	4.30	5.00	4.30	3.30
SD	1.26	.58	.50	1.26	.60	.00	.60	.60
5	4	4	4	3	4	4	2	1
	3	3	3	4	4	4	4	2
Mean	3.50	3.50	3.50	3.50	4.00	4.00	3.00	1.50
SD	.71	.71	.71	.71	.00	.00	1.40	.70
Total								
Mean	3.80	4.10	3.70	3.90	3.90	4.10	3.80	3.40
SD	1.05	1.02	.87	.96	.70	1.00	1.00	1.20

Figure 1

CTAs displayed per group per meeting.



Appendices

Appendix A: Coding Scheme

For coding, it is a simple count of the categories. See the definitions below. Please note the transactions, they are labelled in the protocols that were handed to you.

Categories:

- Assumption recognition

Assumption recognition is the ability to recognize and being aware that you are working with assumptions. When somebody bring an idea or vision in the discussion, it is judged whether the statement is true or not. Assumption recognition is the act of realizing the idea or vision is wrong. The following actions can be taken in response: questioning the idea, stating the assumptions, mentioning that you are aware of the assumptions.

- Argumentation

Argumentation is the construction of an argument. Argumentation uses language to justify or refute a standpoint, with the aim of securing agreement in views (van Eemeren et al., 2015). Even when the information used might be wrong, reasoning to create an argument is a critical thinking activity. Using evidence, even when the evidence is false, showing reasoning in argumentation is a critical thinking skill. This flows from assumption recognition, after which students will for example use sources to build their argument against the assumption, and why/how it might (not) be useful to them.

- Evaluation

Evaluation is the process of checking the statement on its value. According to (Facione, 1990), also known as the Delphi report, evolution of statements is a critical thinking activity and is necessary to judge whether statements are just, reasonable, applicable in the situation and logical. Often, this is done by questioning what the other person has stated, checking for logic, applicability and proper use of the assumptions and facts. Often, it comes down to engaging into a discussion to see the arguments in favour and against the idea. This means that only asking a question is not evaluation. Evaluation is done when the students are bringing positive **and** negative viewpoints.

- Decision making

Decision making is the process of deciding: somebody decides based on argumentation, evaluation, and assumption recognition to form a decision on the statement: whether they believe it or not, and whether they will use it or not. The deciding person will have the cognitive process to decide what they do with the information given. In the coding, also the concluding of something is considered.

-Transaction

A point within the meeting in which the group discusses something with the expert. The end is marked by the introduction of a new point. (Overarching point do not count, one counts the subpoints in that case as a transaction each, e.g. overarching: topic for the research, sub-options are the different topics that the team is considering which are talked about)

Examples

To provide you with the best package and way of thinking for the coding, below I have listed some examples or real utterings of the first recordings with some explanations that hopefully clarify why it is in one category and not the other.

Speaker 3: I know that there are some prototypes that are working, but I think there is no project that is already powering a country or an island. It's more all with research right now.

You can see that the speaker is using reasoning here, without necessarily using any of the keywords.

"It might be a problem if they place a very visible plants next to or in these really attractive locations can hurt tourism really bad"

This is also argumentation as the speaker uses reasoning from a certain point.

It's so little. It's something completely different. And supposedly from what we were discussing it does not seem to affect.

This is decision making as a decision is made whether the previous said thing is enough to be taken into consideration.

So yeah, but I think what you said, I can imagine that has not done much of impact because we have like the top 200 meters of water that are just a massive collection of the sun energy. And if you place, like a relatively small engine, steam engine kind of thing on that massive surface, it's not going to affect that much.

Here, one could argue for assumption and argumentation. The assumption is highlighted in yellow. However, as we are working with a scale (Assumption -> Argumentation -> Evaluation -> Decision Making) we only count the highest achieved in a statement. In this case, only argumentation should be counted.

Speaker 3: It was more a problem that we can implement due to hurricanes since they destroyed already the first version of it in 1910. Oh yeah, something like that. So my point is that in this tropical area, a lot of tropical storms and therefore this is also a technological challenge for this technology.

Speaker 1: That can should be improved.
Speaker 4: Yeah, it's quite hard now.

Speaker 3: But if you are looking at the world cart, you see that there are some regions that are not so, not so much, um, visited by storms and uh, for example, exactly as a quarter the Coriolis uh, workforce a zero. Maybe this might be also a good place.

Here we choose for evaluation, as the students are weighing the positives and negatives in the statements that they make. The evaluation can be spread over multiple statements.

Yeah. Because I do know that the areas around the technology, North America and India are less good because there are a lot of storms like here and here.

Here there is a case of decision making as the group decides on the (un)possibility of the locations.

there is something which makes them vulnerable, I think I guess on sea. But do radiation leaks, they just shut down so much? I don't think the radiation can't spread.

Although not very visible, a statement like this would lead to argumentation, as the speaker is showing reasoning in the statement.

Speaker 3: *Well, I would say that I see that happening on a large scale because eventually, like, if technology develops to such an extent that it will significantly develop maritime transport while also having almost no chance of land causing accidents, being at that place on a larger scale. But for smaller vessels, I wouldn't necessarily say that they would actually use it, because I think that that extra radius of smaller eh smaller vessels would require the advantage of nuclear propulsion.*
Speaker 6: *I think it's definitely a financial question here for smaller vessels. It's it's super expensive to even make such nuclear power. And I think with smaller vessels, it just wouldn't pay off.*

As can be seen here, the speakers are weighting different perspectives, which is evaluation. It should be noted that the evaluation is carried over two statements. This can be the case in multiple happenings, as where one student mentions the positive, and one the negative points.

	Assumption	Argumentation	Evaluation	Decision making	Additional Comments
Transaction 1					
Transaction 2					
Transaction 3					
Transaction 4					
Transaction 5					
Transaction 6					
Transaction 7					
Transaction 8					
Transaction 9					
Transaction 10					
Transaction 11					
Outside marked transaction					

Note for coders: Please mark the statements in yellow in the document that you code. Transactions are marked in the protocols that you have been handed, is something is outside of these, mark it down in the table below and highlight it in a different colour.

Appendix B: Mid-term survey

Instructions: during your project, you had regular encounters with one or more experts. We are interested in your personal opinion on how the experts influenced your teams's thinking about the content of your project. To express your opinion about this, we invite you to write a reflection and respond to the survey items on the next page. Only do the latter AFTER you wrote your reflection.

What is your group number?

Group Number

Think back about the encounters you had up until now and identify a situation in which the expert, in your view, had a significant impact on your team's thinking.

1. What was the situation? (who, what, where, how?)
2. In what way did the situation matter, or why was it significant?
3. How did the situation further affect the course of your group's project?

Now write a short reflection about this situation, using the guiding questions above to structure your narrative.

Write your reflection here

The expert supported my team in recognizing and addressing assumptions.

Totally disagree Totally agree

The expert supported my team in building arguments using literature, logic, and base knowledge.

Totally disagree Totally agree

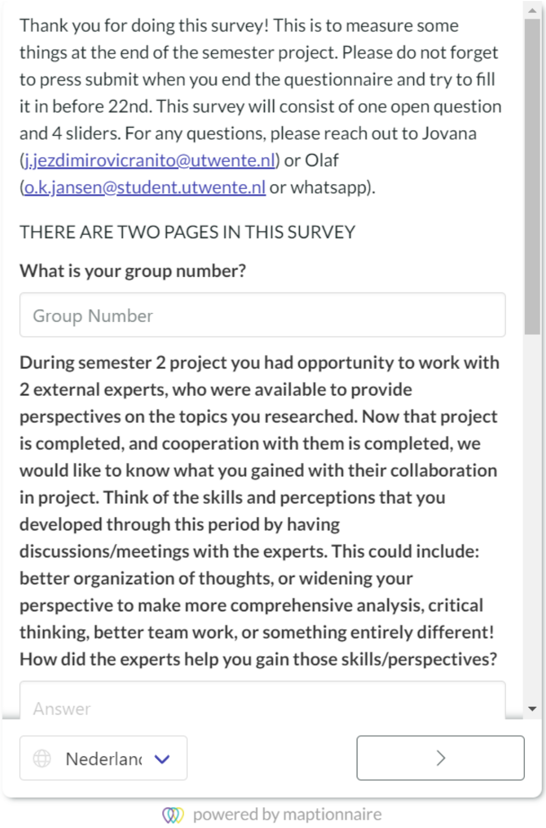
The expert supported my team in evaluating claims; discussing ideas to see the arguments in favour and against these ideas.

Totally disagree Totally agree

The expert supported my team in making decisions based on ideas discussed.

Totally disagree Totally agree

Appendix C: End-term survey



Thank you for doing this survey! This is to measure some things at the end of the semester project. Please do not forget to press submit when you end the questionnaire and try to fill it in before 22nd. This survey will consist of one open question and 4 sliders. For any questions, please reach out to Jovana (j.jezdimirovicranito@utwente.nl) or Olaf (o.k.jansen@student.utwente.nl or whatsapp).

THERE ARE TWO PAGES IN THIS SURVEY

What is your group number?

Group Number

During semester 2 project you had opportunity to work with 2 external experts, who were available to provide perspectives on the topics you researched. Now that project is completed, and cooperation with them is completed, we would like to know what you gained with their collaboration in project. Think of the skills and perceptions that you developed through this period by having discussions/meetings with the experts. This could include: better organization of thoughts, or widening your perspective to make more comprehensive analysis, critical thinking, better team work, or something entirely different! How did the experts help you gain those skills/perspectives?

Answer

Nederlanc

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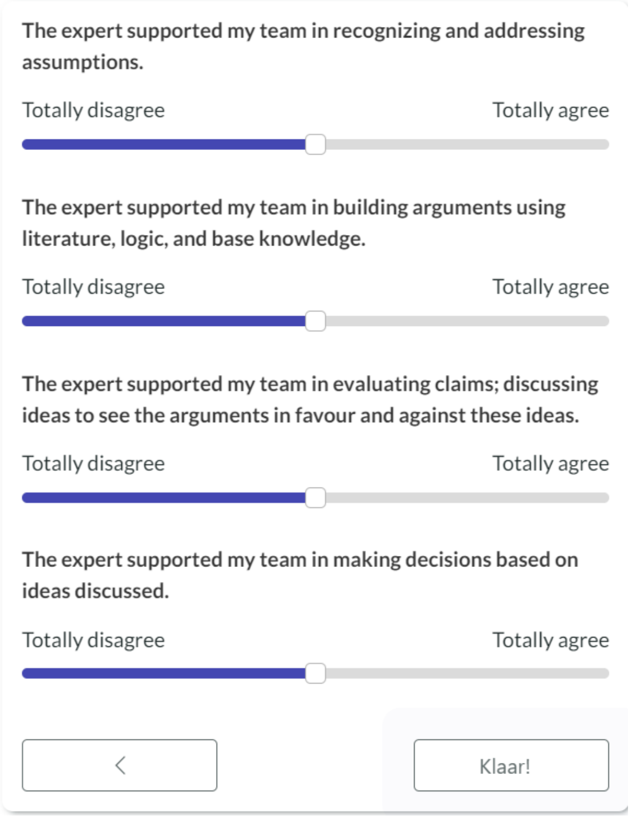

The expert supported my team in recognizing and addressing assumptions.

Totally disagree | Totally agree

The expert supported my team in building arguments using literature, logic, and base knowledge.

Totally disagree | Totally agree

The expert supported my team in evaluating claims; discussing ideas to see the arguments in favour and against these ideas.

Totally disagree | Totally agree

The expert supported my team in making decisions based on ideas discussed.

Totally disagree | Totally agree

Klaar!