Student perceptions on a collaborative engineering design course

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STUDENT PERCEPTIONS ON A COLLABORATIVE ENGINEERING DESIGN COURSE

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ABSTRACT

To adequately prepare engineering students for their professional career, educational institutions offer projects in which students collaboratively solve engineering design problems. It is known from research these projects can lead to a variety of learning outcomes and student experiences. However, studies that provide insights in the influence of different features of an educational design are rare. In the current study we use Cultural Historical Activity Theory (CHAT) as analytical framework to understand how different elements of an educational design affect students' experience. Additionally, we use the notion of contradictions to identify opportunities

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for structural course improvement. Focus groups were conducted with 12 Master students in Aerospace Engineering, that participated in a collaborative engineering design course. During the course, students applied Systems Engineering (SE) and Concurrent Engineering (CE) and worked in the Collaborative Design Laboratory (CDL), which is a state-of-the-art facility that holds a variety of industry relevant tools. It was found that students valued the guidance of their coach and experts, co-located collaboration and the freedom to structure their own process. However, they perceived challenges with regard to adoption of tools in the CDL, sharing their progress with their supervisor, coordination of collaborative efforts and scheduling issues. An analysis using CHAT revealed what contradictions caused these challenges. Finally, recommendations are given on how course structure can be structurally improved.

1 INTRODUCTION

Engineering problems grow increasingly complex, and the ability to design solutions to these problems in a team environment is essential for 21st century engineers [1], [2]. To adequately prepare future engineers for industry, educational institutions adopt pedagogical approaches, such as Project- or Challenge-Based learning, in which students collaboratively solve open-ended problems. However, only providing students with the opportunity to engage in collaborative engineering design activities, does not necessarily lead to effective learning and can lead to varying experiences. According to Cultural Historical Activity Theory (CHAT) [3], an educational activity can be described in terms of interrelated elements that influence outcomes. Contradictions within and between these elements explain how an activity develops over time. Still, studies that reveal how specific elements of an educational design affect students' learning trajectory are scarce [4]. We aim to add to the body of knowledge by conducting focus groups to investigate the impact of different elements of an educational design on student's learning trajectory. We use CHAT to perform a systematic analysis as it not only enables us to outline the elements that mediate an educational activity, but also addresses the complex interrelations between these elements. Additionally, its notion of contradictions provides a tool to identify areas for improvement in a course design.

2 THEORETICAL FRAMEWORK

2.1 Collaborative engineering design

Engineering projects grow increasingly complex [2]. In order to systematically manage this type of problems, Systems Engineering (SE) has been widely adopted in industry. SE can be defined as "*an interdisciplinary approach and means to enable the realization of successful systems*" [5, p. 21] and offers processes, methods and tools that can be leveraged to manage the design and integration of a system thereby taking into account a variety of realistic constraints, such as economic factors, safety, and reliability. In traditional process models, experts design sub-sets of a system relatively independent, while using stand alone tools. However, this separated approach makes it more difficult or even infeasible to integrate the system and find optimal solutions which include insights of the multiple technical and non-technical disciplines involved [6]. To overcome these limitations, industry increasingly makes use of Concurrent Engineering (CE), which is "*a system design practice that encourages immediate collaboration between groups working on interrelated subsystems, so that the whole system can be integrated seamlessly and quickly*" [7, p. 1]. Additionally, tools have been developed to support the continuous integration of a system. Examples are in the Concurrent Design Facility of The European Space Agency (ESA) [6], which provides tools that support the creation of a model that integrates different sub-sets of a design, enable experts to share and present work, and facilitate co-located as well as distributed collaboration.

Educational institutions have to prepare the next generation of engineers for industry by developing education in which they simulate (parts of) professional practices. They increasingly adopt team-based design courses in which students solve complex problems while using industry relevant approaches and tools. In our research we aim to support the design of these courses based on CHAT, which provides a framework for understanding how collaborative engineering design activities can lead to learning.

2.2 Cultural Historical Activity Theory

In CHAT learning is conceptualized as an improved ability to participate in existing cultural practices [8]. For this, learners (subjects) engage in an activity that already exists in a community, because they have a common motive (object). The actions of subjects cannot be understood without the cultural context in which they take place [3]. While acting on the object, the subjects' actions are mediated by interrelated elements. First, there are tools, which are the means that subjects use to work on the object. Furthermore, subjects are mediated by implicit and explicit cultural norms and rules (rules), responsibilities, tasks and power relations (division of labour), and the community that shares the same object (community). These elements and their relations form an activity system (Figure 1). The mediational structure of an activity can be leveraged to promote learning, for example, through letting learners interact with more knowledgeable others [9] or through implementing tools that provide support [10].

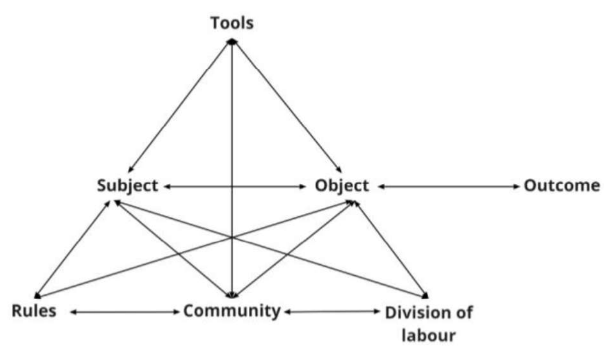

Figure 1. Activity system adapted from Engeström [3]

Activity systems are dynamic in nature and change over time. The source of these changes are contradictions, which are defined as "*historically accumulating structural tensions within and between activity systems*"[11, p. 173]. Analysing contradictions is an essential step toward understanding how activity systems evolve. Moreover, disruptions in the activity systems that are caused by contradictions provide fertile ground for structural improvement. There are four types of contradictions:

1. **Primary contradictions** exist within an element of an activity system, for example, a conferencing tool that cannot be used because the sound bar is not working properly.
2. **Secondary contradictions** emerge between different elements of an activity system for example, when CE rules require experts to integrate their sub-sets of a system in an early stage, but the tools they use do not allow for such integration.
3. **Tertiary contradictions** occur when the object of an activity is more culturally advanced than the dominant form of an activity. For example, when students go to

class their object might be to obtain a good grade, while their teachers instil the more culturally advanced object of skill development.

4. ***Quarternary contradictions*** exist between the central activity system and its neighbouring activity systems. For example, when the learning objectives of a certain course do not match the skills required by industry.

CHAT provides advantages for research on collaborative engineering design education. First, features of an educational activity cannot be examined in isolation as it is a system with complex interrelations. CHAT provides a framework that can help to understand an entire activity system and the interrelations between its elements. Second, the notion of contradictions can be used to trace opportunities for structural improvements in a course design.

In the current study we aim to first identify the benefits and challenges that students perceived during a collaborative engineering design project. Next, we trace back which elements of an activity system are central to challenges and which type of contradiction caused the challenge that was perceived by students. Our study is guided by the following research questions: 1) What benefits and challenges did students encounter during a collaborative engineering design course? 2) What contradictions underlie the challenges that students perceived?

2.3 Study context

The study was conducted within an elective course for Master Students in Aerospace Engineering at Delft University of Technology coined the Collaborative Space Design Project (CSDP). CSDP is a 5EC course that takes place within a period 8 weeks. A mid-term review in week 4 and a final review in week 8 form two major milestones. In this section the activity system of the course will be described (Figure 2).

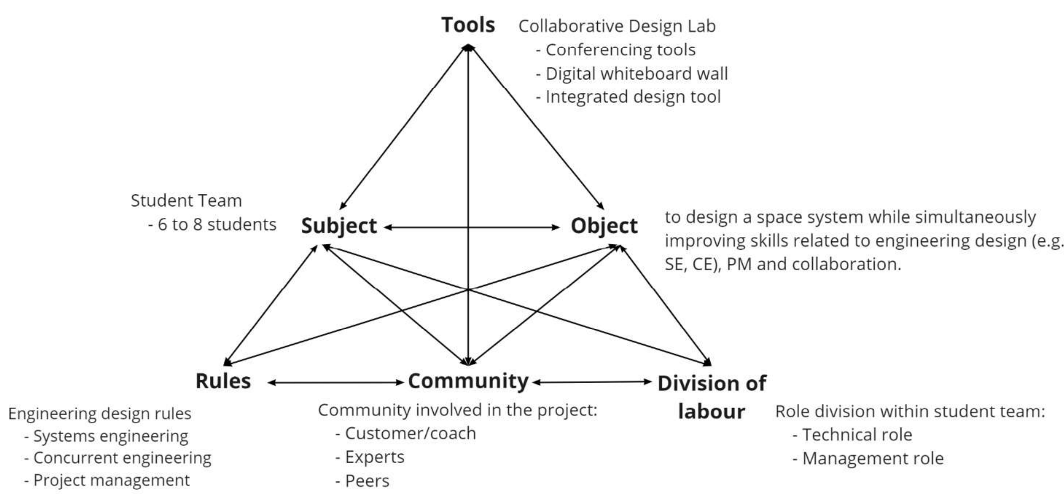

Figure 2. Activity system of CSDP

The ***subjects*** of the activity are three teams of 6 to 8 students. In the CSDP the object is to design a space system while simultaneously improving skills related to engineering design (including SE and CE), project management (PM) and collaboration. Teams work in the Collaborative Design Lab (CDL), which is an environment inspired by ESA's Concurrent Design Facility [6]. It holds a variety of industry relevant ***tools*** that facilitate CE, including: 1) conferencing tools, that allow hybrid meetings, 2) a digital whiteboard wall, which can be used for collecting, organizing and presenting information, and 3) an integrated design tool that allows for the creation and continuous integration of different sub-sets of a design. Teams were offered workshops on CE, SE, and PM, to support the application of these ***rules*** that are used in professional collaborative engineering design practices. Students were free to choose their approach to **division of labour**. However, they were encouraged to assign technical and management roles to each team member. During the process, students interacted with a **community** in several ways. Each team had one or two coaches who also fulfilled on the role of customer. Additionally, experts from industry and peers were invited to the mid-term and final review.

3 METHODOLOGY

3.1 Study design

We conducted focus groups, which are focussed discussions with a small group of people to provide qualitative data to help understand a certain topic [12]. Focus groups can guide the development of an educational program, as it provides insights from the perspective of the target audience.

3.2 Participants

In the academic year 2021-2022, three teams engaged in the CSDP. All teams were invited to participate in the study and 12 out of 21 students enrolled, respectively 3, 4 and 5 for each team. All students were Master Students in Aerospace Engineering, but there were variations in prior experience, study background and nationality.

3.3 Instruments

A semi-structured interview protocol (Appendix A) was constructed. The first part was based on Mwanza's Eight-Step-Model for interpreting the elements of an activity system [13] and addressed the role of each element of CHAT in students' design process. The second part addressed the benefits and challenges that students' encountered during their process, in order to explicate possible contradictions.

3.4 Procedure

Participants engaged in two focus groups; one after the mid-term review and one after the final review. Focus groups were conducted with members that were in the same project team. This led to a total of 6 focus groups. All focus groups were conducted by the first author of this paper and had a duration between 50 and 70 minutes.

3.5 Analysis

Our analysis constituted of two phases. In the first phase, we mapped development of students' activity by identifying features of the course they valued as well as the main challenges they encountered. For this, all focus group recordings were transcribed and analysed in Atlas.ti. We coded all interviews using a coding scheme based on CHAT elements (Appendix B). Next, we collected all benefits and challenges and performed a thematic analysis to cluster them. Only the ones that were mentioned during multiple focus groups were included in the results. In the second phase, we used CHAT as a framework to understand why challenges have emerged. We connected the elements of CHAT that were associated with a certain challenge and assessed what type of contradictions caused the challenge.

4 RESULTS

In this section, we provide an overview of the features of the CSDP that are perceived as beneficial and challenging. Next, we use CHAT's notion of contradictions to understand why these challenges emerged and to identify opportunities for structural improvement of the course.

4.1 Benefits

The design of an activity system can be leveraged to improve learning. In this section, an overview is given of elements of the educational design that were perceived by students as beneficial for learning.

4.1.1. *Freedom to make mistakes*. All student teams appreciated the freedom they were given during the CSDP. This not only gave them the opportunity to pursue a direction that was aligned with their own interests, it also created a valuable learning environment. Students had to choose their own directions and structure their own work processes. They felt that this led to making 'mistakes' that were in hindsight the most important learning moments. One student explained: "*I still think that making the mistake was a learning experience. Tripping over the stone is like: 'Hey, this stone is there*.'" As such, students perceived the way rules were embedded in the activity as positive, as they were given the freedom to choose, try and evaluate their own approach rather than having an imposed set of rules.

4.1.2. *Communication with coach and experts*. Teams mention that they benefitted from the interaction with their coach and experts. One team indicated that they especially valued the informal character of the conversations they had with their coach. It was also mentioned that the mid-term and final review that were attended by the coaches, experts and the other project teams were very useful for collecting feedback. Involvement of the community gave them the opportunity to learn from others that were already more advanced in collaborative engineering design practice.

4.1.3. *Co-located collaboration*. Two teams mentioned that working co-located in the CDL was beneficial for their collaboration. Being together in one room smoothened communication and coordination of tasks among team members. Students perceived that the facilities that were offered positively influenced the division of labour.

4.2 Challenges

The design of a learning activity can also be sub-optimal and elicit challenges for learners. This section provides an overview of these challenges and connects them to CHAT elements.

4.2.1. Technological issues. Two teams mentioned that technological issues made it difficult to use some of the tooling available in the CDL: "*you have to fix problems, they don't work the way you want them to (…) and it slows down things and it is frustrating*." This challenge applies to the tools element of the activity system.

4.2.4. Coordinating cooperative efforts. The process of dividing and integrating work was perceived as challenging by all teams. Team 2 and 3 both indicate that it was difficult to monitor group progress, as there was no formal process for coordinating and organizing work. "*We didn't really have a formal way of tracking tasks. (…) I think the problem was we didn't really have somebody in charge of running these meeting in which you ask: 'how are you doing on this task? And how can we move it forward and all?'.*" This shows that there was a lack of rules on how to organize the division of labour. Team 2 attributed the difficulties in convergence to the fact that they did not have a shared goal in mind: "*The biggest challenge for me during this course was, we split work at the beginning and then that was it for me. So I had the things I said for myself in relation to my part of the thing, but I didn't have a common goal of which I said: 'Okay we need to get there because we are all coming here'.*" This indicated there was division of labour without having clarity on the object of the activity.

4.2.3. Interaction with coach. Teams had the freedom to organize the interaction with their coach. Team 2 struggled with talking about 'the bigger picture' rather than separate issues. Their coach saw their complete design only short before the mid-term review and initiated major revisions: "*I think updates were not exhaustive in that sense, right? (…) I must say, we never showed her what we were actually doing and then she saw everything at once and then she said so many things.*" Team 3 indicated that they had not been pro-active in approaching their coach in the early stage of the project. As a reaction, their coach visited them on his own initiative and asked questions they had not prepared for. Both teams mentioned it was a challenge to provide an overview of their work in early stages of the design. This indicates that teams (subjects) struggle to communicate their work in relation to the project goal (objective) to their coach (community). This challenge disappeared after the mid-term review, where teams presented an overview of their work that provided common ground in later stages.

4.2.2. Adoption of tools. The tools that were available in the CDL were not used extensively by teams. Teams mention that learning to use the tools is a time intensive process and that investing the required time did not feel worth it. In particular the concurrent engineering tool had a steep learning curve and it was more attractive to use familiar tools: "*We haven't really used [the integrated design tool], because we felt it was easier to use Excel. Learning a new software cost time, and we needed more time to focus on our design options and selecting the optimal design*". Meanwhile its application felt inappropriate in early stages of the design, because the number of calculations that needed to be performed and integrated were limited: "*(…) the more in-depth we go in the design, the more useful [the integrated design tool] gets. At this moment we are that shallow that a special tool has no use."* Elements of the activity system, might not resemble the ways of working that are employed in industry and allows subject to rely on familiar tools and rules they know from previous practices.

4.2.1. Course schedule. All teams mentioned that the time frame for the CSDP was tight and the workload was high, especially in combination with other courses. Also, there was overlap between workshops and other courses, which made it impossible for students to attend some of the workshops. The cause is beyond the CSDP activity system and involves activity systems of other courses.

4.3 Contradictions

Challenges that were identified in the first stage, are now understood more thoroughly through the notion of contradictions. For each challenge we have identified an underlying contradiction. Moreover, insights are provided on how to change the activity system in order to improve the course design. A mapping of challenges, contradictions and suggestions for improvement can be found in Appendix C.

First, tools in the CDL did not always work. This is a primary contradiction, thus a solution can be found within a single element, for example replacing malfunctioning software. Second, there is a secondary contradiction between division of labour and rules or object, as some teams have not agreed on rules related to work division or clarified the object of the activity. In addition, there appears to be a secondary contradiction between subjects, community and object, as students struggle to provide an overview of overarching work and goals to their coaches. Solutions to these secondary contradictions should target the interaction between elements. In this specific case subjects should be supported in explicating rules on division of labour. Moreover, the object should be clarified within the group as well as to their coach. A solution is to provide scaffolds that help students to explicate rules and goals. Students indicated that the mid-term review helped in integrating and showing their work. To establish this in an earlier phase of the project, a baseline review can be added in the beginning of the course. Fourth, during the CSDP tools were offered to enable students to simulate (parts of) CE practices from industry. However, students perceived that these did not have sufficient advantages over tools that students were already familiar with, while learning to use them was time consuming. As such, a tertiary contradiction emerged by the activity system of the course and the more advanced activity system in industry, where similar tools are deeply embedded in engineering design practices. Solutions should aim to make the activity system of the course better match the more advanced activity systems of industry. For example, by choosing an object that requires more in depth analysis with elaborate calculations, an integrated design tool could offer more advantages. Finally, a quarternary contradiction emerged as there was overlap between courses and a high combined workload at certain times. A solution requires coordination between multiple activity systems. However, if this is not feasible, it would be possible to record workshops and make the content available for students who could not attend.

These suggestions for improvement can provide support to students to overcome the challenges they perceived during the CSDP. However, it should be taken into account that these attempts should not interfere with the features of the educational design that are currently perceived as beneficial by students. Specifically, students indicated that being able to make mistakes contributed greatly to their learning process. Providing students with more directions, such as scaffolds, could also take away the opportunity of 'tripping over the stone'.

5 SUMMARY

In the current study we aimed to investigate how elements of an educational activity affect students' experience during a collaborative engineering design course using CHAT. It was found that students valued the freedom of choosing their own approach (rules), having a room for co-located collaboration (tools) and interacting with their coach (community). However, students also perceived challenges. Technological issues occurred, which indicated a primary contradiction within the tools element. Other challenges were caused by contradictions between elements. This included difficulties with explicating rules on division of labour and the object within the team and between the team and the coach. Support should target the interrelations between the elements involved. Additionally, tertiary contradiction between the activity system of the course and the more advanced activity system of industry caused hesitance among students in adopting tools in the CDL. A solution should be found in aligning elements of the CSDP's activity system with professional practices. Finally, challenges with conflicting schedules were caused through contradictions between activity systems of multiple courses, and should be solved through coordination between these activity systems.

The current study has some limitations. First, conclusions are based on the redescriptions of events by participants. This is useful for the collection of perspectives, but might not give an accurate reflection of the actual activity. To investigate the impact of different features of an educational design in more depth, methods such as observations could be used to complement focus group results. Second, the results of this study are tied to a specific course and therefore highly context dependent. Similar features in a different course design, might lead to different experiences for students. Therefore, it is important to expand this research to different collaborative engineering design courses, to see if generalisations can be made. Finally, some recommendations are given for course improvement. However, these suggestions are not yet tested in practice. It is important to follow up on these suggestions in order to assess whether they have the desired impact on students' experience.

Despite these limitations, we have shown how CHAT can be used as conceptual framework to address complex interrelations of elements in a course design. Moreover, the notion of contradiction can be used to understand the challenges that are perceived by students and to systematically trace opportunities for course improvement.

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APPENDIX A – INTERVIEW PROTOCOL

Question	CHAT element covered
- Which Bachelor degree did you finish before starting this Master - For which Master's track you are currently enrolled? - How much experience do you have with projects that involve both collaboration and engineering design?	Subject
- What did you expect to learn from the CSDP? - What have you learned during the CSDP?	Object

- What phases did you distinguish in the design process? - What activities did your team perform in each of these phases? - Why did you perform these activities? And why this order?	Rules
- How was the work distributed during these activities? - How did you keep up to date with eachother's progress?	Division of labour

- Where there people involved in the project from outside of your team?
    o Who where those people?
    o How did they contribute to the project?
	Community

- Did you use tools during the project?
    o When did you use those tools?
    o For what purpose did you use these tools?
	Tools

- Which parts of the course did you perceive as beneficial? o Why was this beneficial to you?	Activity system
- Which parts of the course did you perceive as challenging? o Why was this challenging to you?	Activity system/ contradictions
- How could you be supported during these challenges?	Activity system
- Do you have any other recommentions to improve the course? - Is there anything else you would like to share that we have not yet discussed?	Activity system

APPENDIX B – CODING SCHEME[2]

Code	**Applies to quotes that relate to:**	**Example**
Subject	characteristics of one or more students that participate in the project (i.e. the subjects)	"And for another, for me this is a completely different country, with completely different communicative cultures."
Object	the motive to participate in the activity. As the activity is an educational activity, the motive can relate to learning objectives as well as project objective.	"For me it was more about the software and the facilities we could use. So I thought it was nice we could learn something about concurrent facilities that is also used in industry and get experience in it."

[2] Version of coding scheme dated 2022-04-29

Tools	the means that students have used to achieve their objectives.	"We haven't really used [the integrated design tool], because we felt it was easier to use Excel because learning a new software cost time, and we needed more time to focus on our design options and selecting the optimal design"
Rules	the implicit and explicit rules in a community that mediated the activity.	"Yes for example for the orientation [phase],there is of course a certain structure to it when it comes to systems engineering."
Community	the community members that were involved in the activity.	"We invited a couple of other people to the review so at the review those people helped us and we've also scheduled meetings with them this week"
Division of labour	how work and responsibilities were divided among students during the activity.	"In the planning phase we gave each of us, how do you call it? A role, so (..) I was the cost person and [another team member] was the propellant management guy, so each had a subsystem or technical role, so later in the design we picked up those roles"
Contradiction	the indication there might be a contradiction	"the biggest challenge for me during this course was, we split work at the beginning and then that was it for me. So I had the things I said for myself in relation to my part of the thing, but I didn't have a common goal of which I said 'Okay, we need to get there because we are all coming here".

APPENDIX C – CHALLENGES, CONTRADICTIONS AND IMPROVEMENTS

Challenge 1: Technological difficulties when using tools		
Examples of evidence	**Contradiction type**	**Suggestions for improvement**
Team 2. "Yeah I mean because it is hardly even an intuitive thing" (…) "Some of the screens you have no idea where the control comes from" "Yeah, sometimes it is that pc, sometimes it is that pc, you don't know" Team 3. "you have to fix problems, they don't work the way you want them to (…) and it slows down things and it is frustrating."	Primary, tools	Replace malfunctioning software.
Challenge 2: Teams struggle with coordinating cooperative efforts		
Examples of evidence	**Contradiction type**	**Suggestions for improvement**

Team 1. "I think, where we are at this moment working on, is that it [work] is a bit hard to track, to back log so to say." "Yes when we were working on our presentation (…) that gave a good overview. I do not have that overview in our [Google] Drive." Team 2. "The biggest challenge for me during this course was, we split work at the beginning and then that was it for me. So I had the things I said for myself in relation to my part of the thing, but I didn't have a common goal of which I said: 'Okay we need to get there because we are all coming here'." Team 3. "We didn't really have a formal way of tracking tasks. (…) I think the problem was we didn't really have somebody in charge of running these meeting in which you ask: 'how are you doing on this task?"	Secondary, between division of labour and rules or object	Scaffolds by tools or community
Challenge 3: Teams struggle with showing an overview of their work to coaches and experts		
Examples of evidence	**Contradiction type**	**Suggestions for improvement**
Team 2. "I think updates were not exhaustive in that sense, right? (…) I must say, we never showed her what we were actually doing and then she [coach] saw everything at once and then she said so many things." Team 3. "So that is something we probably should have done better, actively communicating with him [the coach] a bit more." (..) Yeah, there was this dynamic that we certainly didn't reach out to him as much as we should have and what i think that happened is that he showed up to our working sessions which was actually nice to get that communication going. But then, because we weren't actually reaching out we could control how and when we actually wanted to have these feedback sessions."	Secondary, subjects, community and object.	Implementing a baseline review
Challenge 4: Teams do not adopt tools that are offered in the CDL and stick to familiar tools.		
Examples of evidence	**Contradiction type**	**Suggestions for improvement**
Team 1: "(…) the more in-depth we go in the design, the more useful [the integrated design tool] gets. At this moment we are that shallow that a special tool has no use." Team 3: "We haven't really used [the integrated design tool], because we felt it was easier to use Excel. Learning a new software cost time, and we needed more time to focus on our design options and selecting the optimal design"	Tertiary, between activity system of current engineering design courses and more advanced engineering practices in industry	Restructure activity system of course so that it is more similar to engineering practices in industry.

Challenge 5: Courses overlap with each other and combined workload is high.		
Examples of evidence	**Contradiction type**	**Suggestions for improvement**
Team 1. “For me it was also a very big challenge that there was an overlap with other subjects.” Team 2. “In my case I had a lot of classes at the same time as the workshops and they were important classes.” Team 3. “I think the workshops on the tools, they are great to expose us to these tools and these ways of working, but in a way I felt a little overwhelmed by some of them. Especially with [the concurrent design tool] I actually missed the first one [workshop] and then it felt like there was no point in trying to get it now and catching up because we had to manage all our other classes.”	Quarternary, between CSDP and other courses’ activity system	Coordination of schedules between courses, record workshops