LOCAL RESILIENCE STRATEGIES FOR COVID19 – A PBL ENGINEERING CASE STUDY

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ABSTRACT

The increasing relevance of uncertainty and complexity provides ongoing and future challenges for engineers. Subsequently, engineers require competencies such as systems thinking, judgement and decision-making in the face of uncertainty or complex problem solving as part of their education. Already, these are part of e.g. the ABET and EUR-ACE standards and the CDIO syllabus. This aligns with emerging trends in engineering education, such as student-centred, active learning and problem-project-based learning (PBL). The aim of this paper is to present a seminar teaching concept and to examine to what extent scenario planning combined with active, PBL and collaborative learning can enable engineering students to develop resilience strategies. Here, resilience describes a system's ability to cope with sudden disturbances by adapting and learning, and resilience strategies represent the ability to design such resilient systems. Based on theoretical concepts of resilience, students had to apply these to a concrete and current problem. Following a PBL approach, an open and ill-defined problem was the starting point for a scenario planning project, where the students had to develop a resilience strategy with regard to the COVID-19 pandemic at a local level. The seminar aimed at developing competencies in resilience thinking and systems thinking. Findings showed that the teaching concept successfully enhanced especially these competencies which are characterized by a high level of complexity, such as reflection, analysis and assessment of resilience-related issues.

KEYWORDS

Resilience, Complexity, Scenario Planning, PBL, Active Learning, Standards: 8, 11

INTRODUCTION

Dealing with uncertainty and complexity are important challenges for engineers in the 21st century (Crawley et al., 2014; Goldberg, Somerville, & Whitney, 2019; Hadgraft & Kolmos, 2020). This requires new competencies such as analysis with uncertainty, dealing with complexity, judgement and decision-making in the face of uncertainty or systems thinking. These are already part of the ABET (2021) or EUR-ACE (2021) accreditation guidelines, but in particular in the CDIO syllabus, referring to 2.1–2.5 (Crawley et al., 2011). However, highly complex or chaotic problems, such as learning from past disasters, are seldom part of engineering curricula (Hadgraft & Kolmos, 2020) and there are shortcomings in terms of awareness of how to deal with and learn from failure (Edmondson & Sherratt, 2022; Goldberg et al., 2019; Pearson et al., 2018). Moreover, studies with engineering students showed that there is little knowledge and understanding about topics such as resilient infrastructures or risk management within their education (Chittoori et al., 2020; Contreras et al., 2020; Rokooei, Vahedifard, & Belay, 2022). Therefore, education needs to better embed the concept of resilience (Kharrazi, Kudo, & Allasiw, 2018; Pearson et al., 2018).

In the summer term of 2021, the seminar “Resilience and socio-technical systems” for engineers in the master's degree programmes in environmental engineering, civil engineering and industrial engineering was used to examine the extent to which student-centred learning approaches, as described in CDIO standard 8, enable students to design resilient systems. Based on the research on the concepts of resilience and different learning strategies, such as active learning and PBL, this paper shows to what extent a scenario analysis combined with an exploratory and collaborative learning approach can enable engineering students to develop resilience strategies on a local level. The teaching concept as well as the students' results are presented and discussed with regard to the learning outcomes.

RESILIENT SYSTEMS

Interdisciplinary and proactive solutions are required to deal with increasing extreme weather events, climate change and urbanization, but also the current pandemic. These need to go beyond safety or risk management which are mainly based on reactive approaches (Hollnagel, 2014; Levin et al., 2021; Park et al., 2013). Therefore, new infrastructures have to be created (informational, social and built), which increase preparedness and response to extreme events (Levin et al., 2021). Here, the concept of resilience applies, which refers to the adaptive capacity of systems or individuals to deal with sudden (unknown) disturbances or disasters. This becomes particularly relevant with regard to complex social-ecological systems, e.g., urban areas, which are based on many interactions of people and the environment (Berkes, 2017). In general, social-ecological resilient systems are characterized by the ability to absorb shocks and stresses, self-organization, learning and adaptation (Carpenter et al., 2001; Folke, 2006). In the face of extreme events, no matter what kind, an effective and adaptive governance with feedback learning and systems thinking is needed (Berkes, 2017; Carpenter et al., 2012; Levin et al., 2021). Moreover, there is evidence that flexible and adaptive processes to local needs build resilience, instead of rigid approaches with fixed procedures (Levin et al., 2021). In general, adaptive governance and adaptive management refer to ongoing problem-solving processes, which prioritize communication, collaboration, learning and adaptive strategies for moving forward (Berkes, 2017). Accordingly, learning from failure is a very important ability when considering resilience.

Dealing with uncertainty and complexity as well as designing resilient systems require corresponding competencies and especially a different way of thinking, which is described as “resilience thinking” (Folke, 2006; Walker & Salt, 2006). Competencies which go along with resilience are for example analysis with uncertainty, dealing with complexity, judgement and decision-making in the face of uncertainty or systems thinking (Francis & Bekera, 2014; Winkens & Leicht-Scholten, 2021). However, there have been few studies on teaching resilience and its underlying concepts and applications (Kharrazi et al., 2018; Plummer, 2010). These can be found especially in the field of environmental education, where Krasny and colleagues (2016; 2009) have been pioneers with regard to the connections between resilience and environmental education (Kharrazi et al., 2018; Plummer, 2010). According to Lundholm and Plummer (2010), education contributes to enabling the building of adaptive capacity regarding the resilience of social-ecological systems. Moreover, the integration of resilience in education can enhancing problem-solving and systems thinking competencies among students by critically analyzing systems' performance. With regard to the relevance of the abovementioned adaptive governance, there are several examples of inadequate educational practices, which mainly focus on students only studying established governance best practices, instead of enabling students to critically assess and maybe change these “best practices” (Nielsen & Havbro Faber, 2021). According to Nielson & Faber (2021), this is, for example, the case in governmental focus on the recovery phase after disruptive events, whereas rather a holistic and system perspective over longer time horizons is required.

However, it is crucial to consider the context in which resilience should be applied and how the concept is used, as resilience has various levels of meanings (Carpenter et al., 2001; Plummer, 2010). For doing so, at first, it has to be clearly defined resilience in terms of what to what and for whom (Carpenter et al., 2001; Meerow, Newell, & Stults, 2016). This makes it complex to teach and to integrate into the learning process. For this purpose, innovative teaching approaches are needed, such as active learning, collaborative learning and problem- and project-based learning (PBL) (Ban et al., 2015; Fazey, 2010). These emerging approaches are also used more often in engineering education (Hadgraft & Kolmos, 2020) and applied within the presented course.

TEACHING CONCEPT

Learning Outcomes and Course Description

The seminar “Resilience and socio-technical systems” takes place annually in summer semester and addresses master students of the study programs environmental engineering, civil engineering and industrial engineering at RWTH Aachen University. The course offers an introduction to current discourses on resilience. Starting with the definition and origin of the term resilience, various interpretations and interdisciplinary approaches are discussed and applied. In the summer 2021, the focus was placed on the current COVID-19 pandemic. This served as a case study to develop a local resilience strategy, thereby gaining competencies in resilience thinking and systems thinking.

Following constructive alignment and Bloom’s taxonomy, intended learning outcomes at course-level (see Table 1) as well as at lesson-level were formulated beforehand (Biggs & Tang, 2011; Bloom, 1956). Contents, teaching concept and assessment were derived from this (Biggs & Tang, 2011; Malmqvist, Edström, & Rosén, 2020).

Table 1. Intended learning outcomes at course-level

Level of Complexity	Taxonomy	Learning Outcomes
	Creating	Students develop local resilience-based approaches with regard to the COVID-19 pandemic.
	Evaluating	Students reflect on resilience-oriented approaches and ways of thinking in their future work as engineers. Moreover, they reflect on the relevance of resilience-oriented approaches to local and global crises.
	Analyzing	Students analyze different scenarios with regard to their resilience effects. They assess existing crisis management approaches regarding their resilience potential, especially using the COVID-19 pandemic as an example.
	Applying	Students apply resilience-oriented approaches to practice-related decisions.
	Understanding	Students outline, compare and contrast different interdisciplinary discourses regarding the concept of resilience. They understand the relevance of crises in the 21st century.
	Remembering	Students define resilience with its various conceptions.

Based on the intended learning outcomes, the course was divided into five topics with their respective problem statements. The selected topics were always related to the COVID-19 pandemic, as this was chosen as a concrete case for this semester:

Crises, disasters and shocks: Why do we have to be sensitized for global risks? Which global risks are increasing regarding their likelihood and impact? Students had to prepare this session by writing on a Miro board what resilience means to them in order to get an insight about their prior knowledge and associations with regard to resilience. Moreover, in this session, different disasters were presented regarding their different aspects of failure, such as the tsunami in 2004 or the Fukushima nuclear disaster.

Resilience and risk: How are resilience and risk related? How can risks be classified? How can resilience of systems be assessed? The concept of resilience was explained to the students, especially with regard to the misunderstandings that accompany it (Kharrazi et al., 2018; Walker, 2020). Furthermore, different types of risks were presented and the focus was placed on unknown risks, such as black swans.

Resilience Engineering: Which technical systems can fail? What relevance does this have for engineers? Students had to prepare this session by reading Park et al. (2013) in order to reflect on the relevance and responsibility of engineers with regard to the failure of technical systems. Based on Hollnagel (2014) relevant abilities of resilient engineering systems were discussed.

Urban resilience: What is the relevance of resilience for urban systems? What challenges does this entail? In terms of the practical application of the resilience concept, urban systems are particularly well suited for this. Based on the studies by Cariolet et al. (2019) and Meerow et al. (2016), the students had to discuss aspects to consider in a resilience assessment for different urban sectors, such as water and energy supply, IT and communication as well as logistics and transport.

Resilience Thinking: How do people perceive risks? What challenges does this pose for resilience? The last session dealt with individual resilience thinking and risk perception. Students had to reflect on their own resilience with regard to dealing with crises as well as their own biases in dealing with probabilities and risk perception. This was done with a special focus on the risk perception regarding COVID-19 (see Dryhurst et al., 2020) and a discussion about the risk communication in Germany.

Active Learning

The course is based on active and problem-based learning combined with collaborative learning, referring to CDIO standard 8 (Malmqvist et al., 2020). By applying active learning, students are required to engage in the learning process and actively reflect on what they are doing, which has shown to positively effect learning outcomes and students' performance (Felder & Brent, 2016; Freeman et al., 2014; Malmqvist et al., 2020; Prince, 2004; Prince & Felder, 2006).

Individual sessions were based on think-pair-share, as this includes individual thinking and therefore leads to greater learning (Felder & Brent, 2016). For doing so, students had to prepare the sessions by reading a paper on their own with a specific question assigned to them. In class, they had to discuss the results together with others. At the end, the group results were presented to the plenary. As the course was conducted online, the group work was organized in breakout sessions using a creative mind mapping tool. In addition, further discussion questions and challenges were posed in the individual sessions, which sometimes had to be answered in the course, others again in small group work by sharing their responses afterwards. This enabled a continuous exchange among students, gaining insights into other perspectives and opinions.

Students were able to voluntarily submit a critical reflection related to each session, which improved the overall grade. However, only a few students made use of this, which is why they are not listed and evaluated here any further.

Problem-based Learning

PBL is a teaching method to engage active learning, which is based on problem orientation and is used to provide the context and motivation for the following learning (Edström & Kolmos, 2014; Prince, 2004). Following a PBL approach, a complex, open-ended and ill-defined real-world problem was the starting point for the course, which was based on a given case. The previously described learning content should guide students to use the provided material, methods and concepts relating to resilience strategies, which promote students' motivation and comprehension (de Graaff & Kolmos, 2003; Prince & Felder, 2006). As there are different PBL practices at the course level, which was studied in a literature review by Chen et al. (2021), the current problem fits both to project-led PBL and PBL for practical capabilities. Furthermore, this could also be framed as challenge-based learning according to Malmqvist et al. (2015). The duration of the course was one semester and students had to work in groups of five. The collaborative team-based learning is important, as the learning process is a social one, where students not only learn from each other, but they also gain competencies in teamwork, communication and collaboration (Edström & Kolmos, 2014). The level of achievement of the intended learning outcomes was assessed via team reports and presentation as well as peer assessment.

Students received the assignment and the case at the beginning of the semester and were able to work on it during the course. During the semester, the students had the opportunity to be advised, ask questions and receive feedback on their previous work.

Case Study

As students should learn resilience and systems thinking by applying scenario planning, an open ill-defined problem is required (Edström & Kolmos, 2014; Jonassen, 2000). Thereby, the COVID-19 pandemic was chosen as a case in order to refer to a current and real-world problem. Within the case, students had the task of developing a local resilience strategy, referring to an adaptive governance, explained in the background section (see Box 1). Thereby, they had to assume the role of a crisis team that is to advise municipal policy. For this, they had to take on different citizen stakeholder perspectives, such as students, service sector employees or nurses. At the same time, the students were given different unknowns to deal with it. For example, it was unclear whether a new (fictitious) mutation of the coronavirus could be transmitted via drinking water. Moreover, some requirements of the governance were given on which students critically had to reflect on regarding their relevance for resilience.

Note that the case is based on the German regulations that were valid during the COVID-19 pandemic. The case was developed in March 2021, the seminar started in April. At that time, tightening measures, such as lockdowns, were linked to incidence, which were set out in a phased plan (see CoronaSchVO, 2021).

Scenario Planning

As it is important for engineers to be able to identify the critical performance measures for a system and not just for a single aspect (Hadgraft & Kolmos, 2020), the task required them to set up different scenarios involving different local stakeholder groups.

Box 1. Case Description

It is May 2021. The third wave has flattened out, retail, outdoor dining, theatres and museums have reopened across the board. No more appointments or negative test results are required. Schools are back in attendance, with high school graduation exams to be written next week. However, a new mutant, R.E.S.21, has recently been discovered in California that is three times more contagious and it is foreseeable that the situation will worsen drastically again in a very short time. It is possible that the new mutation can also be transmitted via groundwater. So far, there is no scientifically proven factual basis for this. More than 60% of the population have been vaccinated, but it is unclear whether the vaccination is effective against the new mutation. Here, too, there is still no scientific evidence.

The federal government has introduced the principle of subsidiarity, according to which the municipalities can decide completely autonomously which measures they take to cope with the crisis. According to the decision of the Federal Constitutional Court, municipalities can even intervene in the fundamental right as long as they are limited in time, purposeful and justified.

Within the framework of a newly appointed crisis team of the Aachen district, various actors meet to discuss the further course of action. In order to strengthen the involvement of the citizens, interest groups from different areas are included. They now have the task of jointly developing a strategy that will have a decisive influence on the next few months. The district will implement your strategy in any case. You will have to put yourself in other perspectives and think through different scenarios to achieve the best possible outcome for everyone.
The following actors are involved:

- two staff members of the Resilience Research Department (mandatory)
- three more stakeholders from different areas, e.g., one school representative of a grammar school, a retail salesperson, a caterer, a nurse etc.

(With the exception of the staff of the Department of Resilience Research, you can choose three other interest groups whose perspective you must represent consistently).

However, your discussions are unfortunately repeatedly interrupted by incoming calls from the City Region Council, which makes the following demands:

1. Every affected industry should receive financial support should you consider a lockdown again.
2. There should be a clear step-by-step plan at which incidence which measures should take effect.
3. It insists on face-to-face teaching and in-presence baccalaureate examinations.
4. an app should be developed, which should contain the functionalities of the Corona App as well as up-to-date information on local retail.
(Think about what you answer and what recommendations you make).

Basically: The focus is always and exclusively on Resilience Thinking! It is not about a medical impact analysis, accordingly, do not get lost in details of medical implications.

To enable resilience thinking among students, several authors recommend the use of scenario planning methods combined with theoretical foundations (Carpenter et al., 2012; Kharrazi et al., 2018). Scenario planning is a suitable method for enhancing creative, critical and systems thinking about possible complex and uncertain futures, based also on different interest groups (Amer, Daim, & Jetter, 2013; Peterson, Cumming, & Carpenter, 2003; van der Heijden, 2005): “In a situation of uncertainty planning becomes learning, which never stops” (van der Heijden, 2005, p. 16). By applying scenario planning the resilience of a system can be explored to various factors (Carpenter et al., 2012). Possible future alternatives are to be considered, which can help to deal with uncertainty. Moreover, it enables to critically question the future and which outcomes are desirable. Therefore, scenario planning provides a holistic perspective on a system with all its interactions and dependencies. Using this approach allows educators to illustrate different probable and yet undesirable futures (Amer et al., 2013; Kharrazi et al., 2018).

As described above, students were given both facts and unknowns. Thereby, students had to identify alternative possible solutions, which often can have different implications for resilience (Carpenter et al., 2012). This enables the students to better understand the dynamics of a system for deriving possible recommendations for action in order to enhance resilience.

RESULTS

Students had to prepare a recorded screencast, in which they present their results to the City Region Council. Here, too, they had to take on the role of the crisis team. To understand the learning process and the resilience strategy of the students in detail, a team report had to be handed in. There, the students had to justify their entire procedure and document the results from their group meetings. After submission, the students had time to view the screencasts of the other groups. In a discussion session, the individual group members were then mixed and tasked with evaluating the results of the other groups with regard to their resilience strategies. In total, four groups (1–4) of five students each submitted a screencast and a report.

The following assessment criteria were applied by the researcher: motivation by explaining the relevance of their resilience strategy, creativity (Did the students deviate from the given guidelines? Did they go beyond the visible reality?), argumentation (Do they justify their strategy? Are they able to convince the audience?), resilience thinking (Did they consider any resilience-related aspects, such as flexibility, worst case scenarios or learning? Is there any longer-term perspective for dealing with such crises?) and reflection (Did they reflect on their own work? What are the weaknesses of their strategy? What would they do differently next time?).

Case Results

The students' results were ambivalent. The work of groups 1 and 2 was overwhelming positive, as they developed a detailed, comprehensible and coherent resilience strategy. Their screencasts, i.e., the presentation for the City Council, were presented in a meaningful way, consistently considering the perspectives of the different stakeholders. Particularly noteworthy were the parts on the development process of the strategy, which show considerable reflection and engagement with the topic. Moreover, they made appropriate assumptions, either based on scientific literature given in the course or on further researched studies by the students. They considered resilience-related aspects, such as flexibility, redundancy, learning and monitoring and multidisciplinary thinking. The students clearly refuted the first two demands of the governance and argued based on resilience why those requirements are not in the sense of learning and flexibility. Both groups performed scenario planning in their work by identifying different alternative solutions with resulting implications for resilience.

Groups 3 and 4 show weaknesses regarding the abovementioned assessment criteria. Their scenarios were based on the chosen requirements of the governance, which characterizes a deductive process. Those were not explained or justified regarding the relevance for resilience or learning. Their strategies focused on robustness rather than resilience, as they did not consider any aspects of flexibility, learning or adaptive capacity. Here, partly, the starting point of their strategies can be considered as scenario planning, but in general they did not follow up on different alternatives and solutions. Furthermore, group 4 closely mirrored the real restrictions and regulations in Germany at that time, with only minor changes to parameters.

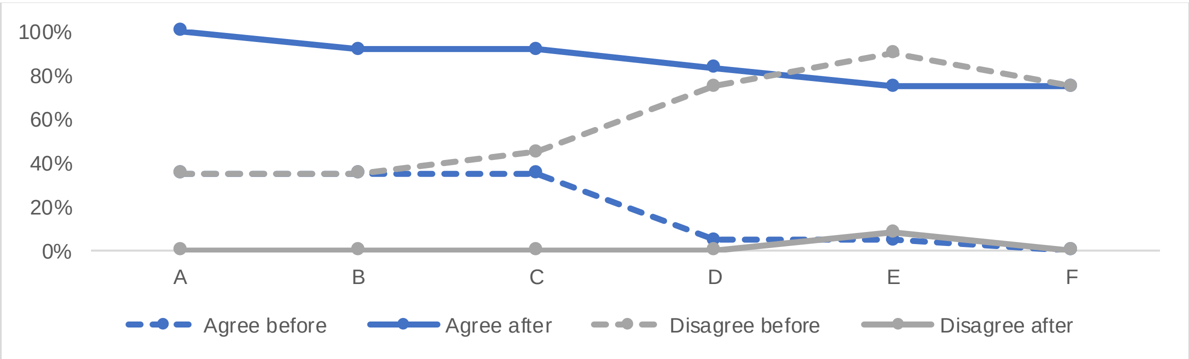
Peer-Assessment and Reflection

In the discussion session, students had to critically reflect on the work of the other groups. They had to discuss strengths and weaknesses of the individual resilience strategies. Moreover, after this session, they had the opportunity to integrate the discussed weaknesses in their final report in order to refine their strategy. Thereby, students not only learn about designing resilient systems, but also on an individual level about learning and learning from failure. By doing so, students could reflect on their learning process and consider what they would do differently.

The results of this peer-review session highlighted that there were significant discrepancies concerning the understanding of resilience. Groups 1 and 2, with a well thought out resilience approach, were criticised by their peers for not having adhered to the prescribed step-by-step plan. So even after having been confronted with resilience for a term, having been explicitly asked to challenge some of the underlying assumptions and being confronted with alternative viewpoints, there was still a deep aversion against deviating from what was seen as the established and expected approach. More so, groups 3 and 4 which primarily presented a robust and stable scenario without further justification did not take up the – justified – criticism in the subsequent reflection. However, the discussion showcased that a justified point of criticism for groups 1 and 2 was that they had not sufficiently thought through transparent (science) communication to the local population. This aspect was taken up and elaborated critically in the subsequent reflection in the report.

Self-Assessment and Learning Outcomes

To follow the CDIO standard 11, a self-assessment survey was conducted in order to measure the extent to which students achieved the intended learning outcomes (Malmqvist et al., 2020). Thereby, the previously targeted learning outcomes of the course were translated into a self-assessment survey for students to complete before the course started and at the end. Students were asked to self-assess (*strongly agree, agree, disagree, strongly disagree, neither*) the following competencies: *I know the concept of resilience and related methods, I understand the relevance of resilience with regard to global risks and crises, I understand the relevance of resilient systems for my work as an engineer, I am able to apply the concept of resilience to different situations, I am able to analyze scenarios with regard to their implications for resilience, I am able to evaluate existing crisis management approaches regarding their potential for resilience.*



A – Knowledge of resilience, methods and tools
B – Understanding the relevance of crises and global risks
C – Understanding the relevance of resilient systems for engineers
D – Applying the concept of resilience to different situations
E – Analyzing scenarios with regard to their implications for resilience
F – Assessing crisis management approaches regarding their resilience potential

Figure 1. Self-assessment results before and after the course

Figure 1 shows the results of the self-assessment before (n=20) and after (n=12) the course. The results are expressed by cumulative percentages of each (strongly) agree and (strongly) disagree. Evidently, after the course all percentages increased. Note that competencies D–F, which are based on a higher complexity level (see Table 1), are consistently rated lower before the course. Moreover, regarding those competencies, students perceive a stronger subjective improvement than at the lower levels A–C.

The results of the self-assessment are only of limited significance and not representative, as not all students completed the second survey and only students' perception is covered. However, the results display a trend concerning competences acquired through the course.

Evaluation

The evaluation of the course took place within the framework of a session in which the students were able to discuss the seminar concept and their acquired competences in groups. They were also asked to record what their personal key takeaways were. The respective results were recorded anonymously, whereby the students could decide which aspects they would discuss again in plenary.

The overall feedback was very positive. The understanding of resilience, dealing with uncertainty, self-reflection and collaborative working were highlighted. The relevance of adaptation and learning and the understanding of resilience as a continuous process were also mentioned. The students appreciated the systematic approach to non-technical problems and especially the topic of urban resilience was positively emphasized, as here concrete and practical case studies could be presented. Beyond urban resilience, however, they wished for more case studies in the other subject areas as well since resilience was understood as a very complex and partly abstract concept. Likewise, the students wished for more time for group work during the sessions. Overall, the feedback session confirmed the improvement of the self-assessed competencies which was surveyed.

DISCUSSION

Kharrazi et al. (2018) found several common misconceptions to the concept of resilience in education: value judgement, adaptability and trade-offs. These result on the one hand from various definitions in literature and the difficulty in measuring resilience and on the other hand from confusing it with the term of robustness and stability (Walker, 2020). Although these were all taken into account in the development of the teaching concept, the students' case results still show deficits, for example with regard to the scenario planning. As explained in the background section, it is crucial to always discuss the resilience of a precise system's function to a precise disturbance (Carpenter et al., 2001; Kharrazi et al., 2018). Moreover, adaptive governance is crucial to dealing with extreme events. In the frame of this course, students had the task to dive into the perspective of this governance. Thereby, students were enabled to critically assess and theoretically change the current COVID-19 management practices in Germany. However, students' results partly do not show detailed analysis of the system's performance. Instead, they concentrated more on stability and robustness.

At the same time, the opportunity to get feedback during the semester was only used by groups 1 and 2, which – perhaps correspondingly – produced strong results. Groups 3 and 4, whose results showed more weaknesses, did not make use of feedback opportunities. The option of supervising was not mandatory, as in PBL it is important that students are the owner of their learning process (Edström & Kolmos, 2014). In a similar pattern, the groups which were already performing very well used the feedback of their peers to further refine their concepts, whereas the weaker groups disregarded it. In summary, in this case study, voluntary feedback and learning opportunities served to further already strong work but had little effect of less well performing students and groups. This aligns with research about students' inability to benefit from assessment feedback by failing to make use of the offered feedback, as there is often a gap between receiving and acting on feedback (Evans, 2013). In future courses it should considered whether feedback sessions are to be mandatory, in an attempt to bridge the gap between achievement levels. As resilience and complexity are difficult to teach (Hadgraft & Kolmos, 2020; Kharrazi et al., 2018), a current, comprehensible and real problem was chosen as the case. However, it also cannot be ruled out that the COVID-19 pandemic, as an event that affects everyone personally. On the one hand, this might have made it difficult to have an objective perspective with regard to resilience perspectives and to break away from current regulations for some students. One the other hand, the case might have contributed to the motivation of the students – in some cases with excellent results.

The results of the self-assessment surveys show a positive trend regarding the development of the intended learning outcomes. The results indicate that especially competencies with a higher level of complexity with regards to resilience were not pronounced before taking the course. At the same time, these competences have developed the most through the course, which suggest a success of the active learning and PBL teaching approaches. However, the considered case presents only a single course. CDIO Standards 8 (Active Learning) and 11 (Learning Assessment) were implemented into the teaching concepts by using PBL. But, as stated by Hadgraft & Kolmos (2020), competencies such as complexity or systems thinking must be embedded in curricula in order to educate engineering students for this purpose. The students' results show that there is a need for enhancing their abilities to deal with complexity and uncertainty, especially in the context of resilience. As it is not possible to provide these abilities completely in a single course, a more systematic and holistic perspective on engineering curricula is required (Hadgraft & Kolmos, 2020; Pearson et al., 2018), which can be provided by a systematic implementation of the CDIO standards.

CONCLUSION

This paper shared the design and results of a student-centred teaching concept, based on active learning, PBL and collaborative learning. CDIO standards 8 (Active Learning) and 11 (Learning Assessment) were implemented by using a PBL approach. Implementing this teaching concept enhanced engineering students' competencies relating to complexity, uncertainty and systems thinking or more concisely: resilience. This is substantiated by students' self-assessment of competence acquisition during the course, whereby in particular those competencies, which refer to a higher complexity level, were marked as developed within the course. The results indicate that the teaching concept and the implementation of active learning and PBL were successful.

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