Student-centered Learning Activities for Key Sustainability Competencies in Online Courses with Many Students

(article starts on next page)

STUDENT-CENTERED LEARNING ACTIVITIES FOR KEY SUSTAINABILITY COMPETENCIES IN ONLINE COURSES WITH MANY STUDENTS

Johan Berg Pettersen

Industrial Ecology Programme and Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU)

Ulrika Lundqvist

Division of Physical Resource Theory, Department of Space, Earth and Environment, Chalmers University of Technology

ABSTRACT

Engineers can make a valuable contribution for a transformation towards a sustainable society. The CDIO framework, where student-active and integrated learning is intrinsic to design-implement activities, therefore also includes sustainability competencies. The purpose of this paper is to evaluate alignment between specific student-centered (active) learning activities used in digital learning environments with many students and engineering competencies for sustainability. Examples of learning activities in two such online courses are presented and evaluated in comparison to the UNESCO key competencies for sustainability. The courses are two undergraduate courses at NTNU where sustainable engineering represents the discipline knowledge. The learning activities were designed for scalability and to be operable within an entirely digital learning environment. The student-centered learning activities that are used in the courses are: i) project-based learning, ii) academic text with peer-review, iii) auto-graded computational assignments, iv) massive online course module, v) flipped classroom. We outline the design of the learning activities and map their alignment with abilities within key sustainability competencies. We discuss the effects of scalability and digital format on learning outcomes, and the student feedback and plans for further development.

KEYWORDS

Engineering education, Systems thinking, Student-centered, CDIO Standards: 1, 2, 3, 6, 7, 8, 11, optional standard 1

INTRODUCTION

There is an urgent need for transformation of society towards sustainable development. Governments all over the world have adopted the UN 2030 Agenda and agreed on the Sustainable Development Goals (SDGs) (UN, 2015). Engineers have a critical role and can make a valuable contribution to such a transformation and therefore engineering education must be designed to support learning of sustainability competencies. In line with these needs, the CDIO framework for engineering education has been updated to include sustainability. Sustainability is now explicit in most of the twelve core CDIO Standards 3.0 (Malmqvist, Edström, & Rosén, 2020a) and in addition there is an optional standard for sustainable development (Malmqvist, Edström, Rosén, et al., 2020b). This makes an important difference since these standards define the distinguishing features of a CDIO program, serve as guidelines for educational reform, enable benchmarking with other CDIO programs and provide a tool for self-evaluation-based continuous improvement. In line with this change of the Standards, the CDIO Syllabus has been updated to version 3.0 and sustainability is now integrated to a larger extent than before (Malmqvist et al., 2022). The CDIO Syllabus is a list of topics that indicate desirable competences of graduating engineers that can be used as a source of inspiration or as a frame of reference, for instance when selecting and formulating learning outcomes for curricula and courses.

The update of the CDIO Syllabus 3.0 was preceded by an evaluation of the CDIO Syllabus 2.0 compared to the Unesco key competencies for sustainability (Rosén et al., 2019). The integration of sustainability into the CDIO Syllabus 3.0 was then to large extent influenced by these key competencies for sustainability but also by other key competency frameworks (EOP, 2020; Lozano et al., 2017; Wiek et al., 2011, 2016).

According to constructive alignment (Biggs & Tang, 2007), learning activities in a course should be designed to activate students and support their learning of the intended learning outcomes for the course, i.e., students should practice on what they should be able to do. Another way to frame this intention is that the teaching should be *student-centered*. Student-centered teaching places more of the learning responsibility to the student (Wright, 2011), allowing students to take control of the learning by active participation, or self-education. Thus, a challenge for teachers is how to design appropriate learning activities to support key competencies for sustainability. Examples of appropriate learning activities can be found in previous research on education for sustainable development within MPhil (Cruickshank & Fenner, 2012) and engineering programs (Segalàs et al., 2009).

Digital learning environments represent an additional challenge for student-centered learning. The digitalization of education was accelerated due to the corona pandemic and online teaching is still used occasionally also in campus located education and is promoted when the pedagogical benefits are considered to dominate compared to classroom teaching. Another constant pressure on universities, due to economic reasons, is to deliver education in a more resource-efficient way, which can influence the number of students that are expected to take a course at the same time. One benefit of online courses is that they can be scalable, i.e., have many students. Hence, there is a need for good examples of appropriate learning activities for key competencies for sustainability in the setting of online courses with many students.

In this paper, we describe several student-centered learning activities that have been used in courses to support key competencies for sustainability. The activities have been employed in two undergraduate courses at the Norwegian University of Science and Technology (NTNU). The courses cover sustainable engineering, have been given in a digital format, and serve 250 and 1000 students respectively. Our aim is to discuss the scalability of the individual learning activities and to evaluate the extent to which the intended sustainability competencies can be fulfilled with the portfolio of activities. To do this we conduct an initial, qualitative mapping of the applied student-centered learning activities towards UNESCO's key sustainability competencies and affiliated abilities. We proceed to discuss the principal alignment of the scalable activities towards abilities, based on qualitative considerations, literature and specific student feedback. To aid any study program seeking to integrate competencies for sustainability in activities and learning outcomes within a CDIO framework, we include a short description of the learning activities and how they relate to the CDIO Standards. Finally, we summarize student feedback and potential further development of the activities.

BACKGROUND

The courses in our case are described in Table 1 and the course content can be described as *sustainable engineering*. Both courses were conducted at NTNU entirely within a digital learning environment in 2022, entailing primarily group work and activities suited for self-guided and student-centered learning. The specific learning activities follow the table.

Table 1. The Courses

Course	Brief context and description
TEP4295 *Sustainable engineering*	An undergraduate course at 7.5 ECTS offered to 2nd and 3rd year students in 5-year integrated MSc programs, in total 200-250 students. The course covers concepts, assessment methods and strategies for sustainability. The course has been transformed from a teacher-oriented format last lectured in spring 2020, to a fully online version in 2021 and 2022 as a hybrid (streamed) course in 2023.
INGX2300 *Engineering systems thinking*	An undergraduate course at 10 ECTS offered in the final semester to all NTNU's bachelor engineering programs, in total 1 000 students divided between three campuses (Trondheim, Gjøvik, Ålesund). The course covers innovation, entrepreneurship, economic management, and sustainable engineering. The course has been conducted as one digital, shared course across all study programs since spring of 2022.

Project-Based Learning (INGX2300), where students work in inter-disciplinary groups of 5-6 members to develop new business concepts within a given theme (Energy storage, Smart City, etc.). The project requires creativity and strategic thinking to develop a business concept, and discipline knowledge from the course to evaluate market and sustainability potential of their concept. Scenario-thinking is specifically asked for in this assignment. The project assignment includes several deliverables over the 8-week period, amongst them is a collaboration agreement, midterm oral pitch, and final report.

Academic Text with Peer Review, where students write a short academic text (1000-1200 words) about definitions of sustainability and how the students consider sustainable engineering to be relevant for their profession. They provide anonymous written feedback to their peers on draft papers, before revising their own paper based on the rubric comments they receive themselves. Peer assessment is facilitated by a commercial online education management system (*Eduflow*), for the papers as well as in group assignments to correct and comment on a rather strictly defined scenario model exercise (TEP4295). Direct peer feedback is also applied, wherein the student groups comment orally on pitch presentations of their peer groups' business in the project-based learning activity (INGX2300).

Auto-graded Computational Assignments, made using *nb-grader*, a tool to make and grade Jupyter Notebooks (Jupyter et al., 2019). *Training notebooks* are setup with local, instant feedback and contain mimicked examples from the textbook, including video material and textbook links. *Assignment notebooks* are graded on the central server with 60 min delay to avoid overload. All assignments are identical with seed randomization and solving them involves programming and linear algebra. Students are encouraged to work together to solve the problems as no student will share the same numerical solution.

Massive Online Course Content holds the non-computational curriculum. Built using *Eduflow*, it contains reading and video material for self-paced individual and group study. The format allows a combination of ways to illustrate and teach core sustainability concepts and strategies, through reflection questions, discussion boards, quizzes, etc.

Flipped Classroom Problems, in-class activity (Akçayır & Akçayır, 2018) and spaces to discuss and reflect contents of the online course module and computational materials. Each session is described in the course learning platform outlining i) preparatory video and reading material, ii) problem description, and iii) digital tools, iv) digital channels for audio/video and written communication. Both tailor-made (simplistic databases for life cycle assessment and input-output analysis) and third-party tools (climate policy simulator) are used in the flipped classrooms. The problems include simplified life cycle assessment (plastic and natural Christmas trees), allocation in life cycle assessment (milk farm), material flow analysis (clothes in Norway), carbon footprint (of a student), energy assessment (windfarm concept), industrial symbiosis (for a specific industry cluster), and global climate policy (how to stay under 1.5 degrees). The flipped classrooms have been conducted in purely online formats (INGX2300) and hybrid streams (e.g., TEP4295 in 2023). Online video communication platforms are used to initiate the session, provide the online workspace (Zoom), and communication channel (discussion board).

METHOD

Qualitative mapping was conducted to evaluate alignment between the learning activities towards the intended sustainability competencies and affiliated abilities in Table 2. We use the UNESCO key competencies for sustainability. These have largely influenced how sustainability is integrated in the CDIO Syllabus 3.0, and have beenderived by synthesis of published sustainability education research (Haan, 2010; Rieckmann, 2012; Wiek et al., 2011).

We aim to discuss the scalability of the learning outcomes, i.e., how well the outcomes can be supported when conducting the activity for many students. The discussion is based on theory from literature and qualitative considerations from the teacher’s own observations, using for review and interpretation student feedback received from the last two years. There has been written feedback from the students in completed surveys as well as oral feedback in dialogue with the class and class representatives during course evaluation. Large variation in exam format over the last three years hamper a more quantitative assessment of learning outcomes.

Finally, in the evaluation of the alignment of the learning activities to the CDIO Standards 3.0, the focus is on the content in the Standards about competencies and learning activities as well as sustainability.

Table 2. The UNESCO Key Competencies for Sustainability (Unesco, 2017)

No.	Competency	Related abilities
1	Systems thinking competency	a. recognize and understand relationships; b. analyse complex systems; c. think of how systems are embedded within different domains and different scales; d. deal with uncertainty.
2	Anticipatory competency	a. understand and evaluate multiple futures – possible, probable and desirable; b. create one’s own visions for the future;

		c. apply the precautionary principle; d. assess the consequences of actions; e. deal with risks and changes.
3	Normative competency	a. understand and reflect on the norms and values that underlie one’s actions; b. negotiate sustainability values, principles, goals, and targets, in a context of conflicts of interests and trade-offs, uncertain knowledge and contradictions.
4	Strategic competency	a. collectively develop and implement innovative actions that further sustainability at the local level and further afield.
5	Collaboration competency	a. learn from others; b. understand and respect the needs, perspectives and actions of others (empathy); c. understand, relate to and be sensitive to others (empathic leadership); d. deal with conflicts in a group; e. facilitate collaborative and participatory problem solving.
6	Critical thinking competency	a. question norms, practices and opinions; b. reflect on own one’s values, perceptions and actions; c. take a position in the sustainability discourse.
7	Self-awareness competency	a. reflect on one’s own role in the local community and (global) society; b. continually evaluate and further motivate one’s actions; c. deal with one’s feelings and desires.
8	Integrated problem-solving competency	a. apply different problem-solving frameworks to complex sustainability problems and develop viable, inclusive and equitable solution options that promote sustainable development, integrating the abovementioned competences.

RESULTS

Learning Activities and Alignment to Key Competencies for Sustainability

An evaluation of the learning activities and their contribution to key competencies for sustainability is presented in Table 3. Before a further description of the mapping, we make the observation that, looking across all learning activities, every individual ability is answered by at least one activity and most abilities align with more than one activity.

Table 3. Alignment of Learning Activity and UNESCO Key Sustainability Competencies

	Learning activity *Letters refer to related abilities under each competency. Abilities not aligned with the specific learning activity is marked in strike-through, red letters.*				
Sustainability competencies	Project-based learning	Academic text with peer review	Auto-graded computational assignments	Massive online course material	Flipped classroom problems
1.Systems thinking competency	a, b, c, d	~~a, b,~~ c, ~~d~~	a, b, ~~c,~~ d	~~a, b, c, d~~	a, b, c, d
2.Anticipatory competency	a, b, c, ~~d,~~ e	~~a,~~ b, c, ~~d, e~~	~~a, b, c,~~ d, ~~e~~	~~a, b, c, d, e~~	a, b, ~~c,~~ d ~~, e~~
3.Normative competency	~~a,~~ b	a, ~~b~~	~~a, b~~	a, ~~b~~	a, b
4.Strategic competency	a	~~a~~	~~a~~	~~a~~	a

5.Collaboration competency	a, b, c, d, e	a, ~~b, c, d, e~~	~~a, b, c, d, e~~	~~a, b, c, d, e~~	a, b, c, d, e
6.Critical thinking competency	a, b, c	a, b, c	~~a, b, c~~	~~a,~~ b, ~~c~~	a, b, c
7.Self-awareness competency	a, b, c	a, ~~b,~~ c	~~a, b, c~~	a, ~~b, c~~	a, ~~b,~~ c
8.Integrated problem-solving competency	a	~~a~~	~~a~~	~~a~~	a

From Table 3 is appears the massive online course module and the auto-graded assignments add only marginally to the competencies. The massive online course module does contain questions and tasks that require normative and critical thinking, and self-reflection. Student participation in these supplements their learning towards the affiliated competencies. Still, the online course material and the computational assignments are mainly discipline oriented and only to a very limited extent allow for competency integration. They may therefore be defined as pre-requisites for the other, more experiential activity. Still, the online format maximizes accessibility to the material and self-regulation of learning is supported when students can revisit the material multiple times, both in preparation of class and after (Jovanovic et al., 2019).

The format of the computational assignments allows for auto-grading and resource benefits. It facilitates grading of computational assignments in large courses, with an instantaneous or relatively fast response that is formative in nature and supports self-paced learning. The computational assignments include analysis of systems and system relations at different scales (systems thinking competency), including models of consequences of actions (anticipatory competence). The format of the assignments is similar to the *many small programs*-concept that has been found to be able to improve course experience, reduce stress and improve fulfillment of learning outcomes (Allen et al., 2018).

Integrated problem-solving competency, i.e., the opportunity to combine and develop all specific competence areas, is only represented in the problem-based activities, thus in the project work and the flipped classroom sessions. Besides supporting the key competencies, problem-based learning can benefit content knowledge, learning strategies, skills and motivation (Guo et al., 2020). The project-based activity is intended to allow students to apply integrated learning in a concrete case, with emphasis on innovation and entrepreneurial efforts. The groups are asked to evaluate and negotiate sustainability and market aspects, thereby also reflecting on values and perceptions and take a position (i.e., critical thinking competency). The project-based approach has been proposed as particularly relevant for sustainable development in engineering education (Lehmann et al., 2008). The project activity includes midterm presentations wherein groups present their concepts to each other and the teacher for feedback, supporting the ability to continually evaluate and further motivate one's actions.

Peer assessments can provide resource savings for the teacher. Few studies apply peer assessment in comprehensive learning environments such as collaborative work and problem-based learning (Ashenafi, 2017), which is unfortunate as peer feedback can increase student engagement in a task (Barroso & Morgan, 2011). It can make students think longer about the input they receive (and give), which is found to facilitate deep learning on the discipline concepts (Filius et al., 2018). Moreover, it gives experience in review as part of the systems engineering protocol. Peer assessment is also applied in the academic text that students write, which – although anonymous – allows learning from each other (i.e., collaboration competency). Peer review also requires engaging in normative and critical considerations and reflection on own roles and perspectives, thus supporting many key competencies.

The flipped classroom sessions allow for integrated problem solving and therefore link with most of the competence abilities. In one of the flipped classrooms the student groups are assigned a random country. They should then gather sustainability information about the country, such as human development index, gross domestic product, energy and health statistics, after which they are asked to negotiate within their group a global policy for achieving the Paris target of 1.5 degrees considering these other 'national' sustainability interests and needs. Policy strategies are tested and validated using a global climate policy simulator (En-ROADS). Finally, groups present their policies in open plenary and discuss them from the perspective of the countries present. The climate policy example, as well as the other flipped classroom activity, involves applying a holistic perspective and considers system effects of element changes (i.e., systems thinking competency). Moreover, it requires understanding and negotiating views and values, i.e., normative competency. The flipped classroom sessions should provide a critical and integrated dimension (problem solving competency) to the curriculum through peer-assisted, collaborative, and cooperative learning activities (which should develop their collaboration competency). Although many complete the tasks individually, the activity is designed as group work to think strategically about sustainable development (i.e., strategic competency). The design of the activity allows them to question norms and opinions (normative competency). Two of the flipped classroom problems involve the role of citizens and consumers, offering a venue to reflect on the role of local and global communities (i.e., self-awareness competency). The flipped classroom sessions thereby answer to most of the key engineering competencies, where the full list of alignments towards the UNESCO competency abilities is outlined in Table 3. The flipped classroom sessions require development of relatively simple system representations or use of predefined simulation models. These are to a lesser extent linked with anticipatory competency; given that they do not consider precautionary measures and risks, and in self-awareness competency; given that their policies concern other citizens.

Generally, the use of problem-based assignments can enhance capacity for flexible knowledge with new information acquired through self-directed learning (Bishop & Verleger, 2013). Flipped classroom can help build a positive social learning environment (Steen-Utheim & Foldnes, 2018). This is highly useful in a course such as the ones we describe here since it brings together multiple student groups, but experience also shows that it is more difficult to conduct in purely digital settings (Kim et al., 2014). Concrete feedback from the students was that they would strongly prefer to have a physical venue for the flipped classroom. They also pointed to success factors reported by others for flipped classroom (Gilboy et al., 2015; Rotellar & Cain, 2016): more clear and concise pre-class preparations (what should be known, not what should be done), use of check-in assessment (quiz or checklist), and a suitable work effort within the given time window, and effective digital and other in-class learning materials.

CDIO Standards

This section references first the alignment between the learning activities and the CDIO Standards 3.0, followed by a short discussion of relevance for Optional Standards 3.0.

The discipline knowledge in the courses is in support of environmental, social and economic sustainability knowledge in the context of engineering education (Standard 1: The context), supporting the rational that for engineers to contribute to develop appropriate technical solutions they need to understand the implications technology has on sustainability factors

(Standard 2: Learning outcomes). The student-centered learning activities are particularly relevant for personal skills, and through collaborative and peer-to-peer evaluation to develop concepts, competencies, and interpersonal skills (Standard 3: Integrated curriculum).

Learning workspaces, especially the digital learning environment, is intrinsic to the cases that we describe (Standard 6: Engineering learning workspaces). Activities are conducted within digital environments and use various digital tools, with problem-based cases providing integrated learning experiences (Standard 7: Integrated learning experiences). The open, interdisciplinary problem-based assignments are student-centered and experiential (Standard 8: Active learning). The experience from conducting these exercises in the course is that the non-disciplinary learning is more challenging to achieve and leading to most of the practical obstacles (peer feedback, group formation, role clarification, collaboration agreements, fair distribution of workload, etc). According to Standard 8, teaching and learning should be based on active and experiential learning methods to engage students directly in thinking and problem-solving activities. A variety of learning assessment methods is applied, including formative sense peer-to-peer evaluation, quizzes, auto-grading and oral feedback, and as summative the final exam and the final report (Standard 11: Learning assessment).

The learning activities can contribute significantly to the fulfilment of CDIO Optional Standards 3.0, as they allow students to meet a course rich with sustainability learning experiences (Optional 1), apply simulation mathematics (Optional 2), and work with engineering entrepreneurship (Optional 3), all of which are competencies required to address sustainable engineering.

DISCUSSION

Scalability of Student-centered Activity and Key Abilities

Rather than one-way communication from an active teacher to passive students, student-centered learning practices shall engage students in autonomous learning and active participants in the learning process, as individuals and groups (Jones, 2007). Scalable student-centered learning activities are operable also with large student numbers and should encourage durable and deeper learning through promotion of important life-long learning competence such as growth mindsets, self-efficacy, and self-regulation, all of which also increase student retention and success (Hempel et al., 2020). We can easily confirm that these outcomes align with the sustainability competencies in Table 2, including collaboration competency (learn from others) and self-awareness (deal with one’s feelings and desires).

The activities in Table 3 are designed for scale, i.e., they should facilitate close to endless number of students. With the online platform, peer review is highly scalable, while also enhancing active, reflective, and participatory learning (Colbert & Arboleda, 2016). Similarly, the massive online course material and the auto-graded computation assignments have no limitation except for managing and communicating registration and acceptance (and remind those that do not pass). This leaves the two project-oriented activities: the project-based assignment and the flipped classroom sessions. We start with the latter.

High-quality learning materials, experiential training workshops, and ongoing classroom-based and online support is key for success in scaling education programs, yet must also be followed by positive interaction and social participation in the learning activity (Colbert & Arboleda, 2016).

There are challenges with achieving active participation in digital learning environments. Enforcing mechanisms, or positive alignment, may be used to improve participation, such as improving the pre-class and preparatory material (Han & Klein, 2019; Rotellar & Cain, 2016). Certain trades are made between the scalability of the online format and the benefits of physical meeting rooms, as described by Kim et al. (2014). In physical flipped classrooms, upscaling requires venues, as well as an increase in support form lecture assistants or conducting course parallels to handle the large student numbers. This is especially required INGX2300 which distribute across campuses.

The project-based assignment includes a final report that is graded. The student activity itself scales well and can be supported using digital platforms. Peer-review and collective evaluation is used for the midterm presentation, both are scalable, formative evaluations. The major limit for scaling the project-based assignment is the summative grading and project support.

Synthesizing Table 3 we find that excluding the problem-based activities, i.e., project-based learning and the flipped classrooms, all the abilities under systems thinking competency will be met by one of the other three activity types. Within anticipatory competency, ability 2a and 2e are only met by the project-based activities, and the same is seen for the normative competency 3b (negotiate values). To support understanding of various futures (2a) and to deal with risks (2e) and trade-offs requires the involvement in the two less scalable activities. The same concerns strategic competency (4a), and most of the abilities under collaborative competencies (5b, 5c, 5d, 5e) except for learning from others. The three abilities within critical thinking competency are answered by the scalable activities in concert, as well as by the two problem-based activities. One of the abilities under self-awareness competency, 7b (evaluate and motivate one's action), and the integrated problem-solving ability (8a), is not answered by any of the scalable activities and requires either project-based activity or flipped classroom activity.

The TEP4295 course has been provided also as an online self-study course using the same learning materials. This implies that all parts of the course, including the flipped classroom sessions, can be conducted without synchronous and limited guidance. Students that follow the self-study version report lower motivation to complete the course. The grade outcomes are comparable in the online self-study and the conventional course formats, even if student numbers in the self-study course are too low to allow fair comparison. However, the lack of guidance and teacher attention is frequently pointed out by the students that feel that the outcome is limited by the digital format.

Student Feedback and Changes for Next Year

Student feedback provides a valuable input to further develop the activities and ensure alignment. This section summarizes the student feedback, as interpreted by the course administrator.

Students respond positively to the text assignment with peer review. They are frequently surprised by the request to write a subjective text in an engineering course, which many say they have not done since high school. In other words, the engineering students consider their field a technical and science-oriented one and extend this also to sustainable engineering. This emphasizes the need to integrate non-technical and organizational aspects into engineering education to better the competencies for sustainability (Segalàs et al., 2009). Another unexpected, yet more frustrating observation, is made by the students for the auto-graded computation assignments, when they realize they need to program in a course on sustainability.

Arguably some of the assignments were in development into the course period and were also updated several times due to errors in the problems or solutions, causing students to question the correctness of the assignments and grader. We note here that self-efficacy may be specific to discipline, so that efficacy in one discipline does not necessarily transfer to another (Hempel et al., 2020). Having a growth mindset and self-reliance is important for life-long learning, and particularly so for sustainable engineering where future solutions must be different from those we see today. The need to learn technical skills, such as programming, to work with less technical problems, such as sustainability, makes for a very integrative learning experience. Changes to the computational assignments involve connecting them to the flipped classroom sessions, and these are described further below.

The massive online course material is generally received with positive feedback. It appears many students speed their way through the material and consider it a replacement rather than supplement for the textbook. The module contains also questions for reflection and discussion, discussion boards and quizzes, and many of these are not completed or the pedagogical effect of them is missed, indicating improvement potentials in the design, and perhaps also in the on-boarding of students. This observation supports what we stated earlier that the online course material rather can be considered a pre-requisite for the other learning activities rather than an independent activity.

The most appreciated activity is the project-based assignment. It offers the students freedom to pursue their own interest within the bounds of the problem and build an integrated and collaborative learning experience. Surveys confirm it is the assignment they invest most time in. It forms part of their summative grade, which for many of the students is highly motivating. A physical start-up was recommended after the first year in 2022, to initiate group formation and start the concept development.

The most challenging activity is the flipped classroom. The students are not provided with solutions for the problems presented in these sessions, although students generally ask for them. Active group formation is rather low, where few students end up working in groups and many do not complete the problems. The importance of alignment between the elements of a learning activity, and for flipped classroom also preparatory material, digital tools, problem description etc, is a recurring issue and has been reported by many (Gilboy et al., 2015; Reeves, 2006; Rotellar & Cain, 2016). Improvements to these will add to the value of the flipped classroom sessions. Many students reported frustration with not learning much from these sessions, and that they had to learn for themselves afterwards. It is well known that flipped classroom does not suit everyone and tends to polarize a class of students (Stöhr et al., 2020). On-boarding and building a consensus on the outcomes of flipped classroom is vital for it to activate students and support the intended learning outcome (Gilboy et al., 2015). A core conclusion from the feedback is to ensure buy-in and explain the connections between the integrated learning experience and sustainability competencies (Davidson et al., 2021). A very concrete opportunity to increase the perceived value of the flipped classrooms is to connect them to the computation assignments, principally making the computational assignments part of the preparatory material for the flipped classroom sessions. This can be seen as constructing a stricter alignment between the computational assignments (which involve the mathematics of sustainability assessment), and the flipped classroom activities (which focus on the concepts and theoretical aspects of the assessment methodology). Another concrete opportunity is to develop a form of check-in assessment to motivate preparation and reveal gaps. Both check-in quiz and integration with computational assignments were implemented for 2023. Feedback from the (hybrid) revised flipped classroom sessions in TEP4295 included the need to more concretely integrate anticipatory, normative and critical thinking, and allow more collaborative activity. As outlined above, the ultimate development of these competencies is hampered by the digital format. Further development should seek formats that involve increased dialogue and collaboration.

CONCLUSIONS

We identify many alignments between the student-centered learning activities and the full list of key sustainability competencies and related abilities in education for sustainable development. There are multiple connections between the activities, meaning that several activities match each ability. This can be seen as a strength in the courses, that the courses offer a portfolio of activities to support a multitude of sustainability competencies.

The major competence building is offered by the two activities that are more difficult to scale to many students, i.e., the project-based assignment and the flipped classrooms. Successful scaling of these will rely on better on-boarding students to the intention of the activities to let them take more active ownership of their education. Increasing the resource effectivity of education is a general challenge. Scaling higher education therefore is not a challenge specific to sustainability education, however, it is an area that is not well researched. The examples that we describe in this paper highlight that measures for successful scaling exist, e.g., auto-grading assignments and peer review. These measures also closely resemble what has been proposed elsewhere as measures to improve student success. Scalable student-centered learning activities should promote important life-long learning competence: growth mindsets, self-efficacy, and self-regulation (Hempel et al., 2020), which would also add to the resource efficiency of the activities. To revert to the idea of student-centered learning, it should involve practices to engage students in autonomous learning and active participation (Jones, 2007). Successful scaling of the activity require changes in both teaching and learning activities.

FINANCIAL SUPPORT ACKNOWLEDGEMENTS

Pettersen is partly funded by the project “Sustainable engineering – EVU” by Diku (Norwegian Agency for International Cooperation and Quality Enhancement in Higher Education) under grant Fleks 2020/10120. Lundqvist received no financial support for this work.

REFERENCES

Akçayır, G., & Akçayır, M. (2018). The flipped classroom: A review of its advantages and challenges. *Computers and Education*, *126*(July), 334–345. https://doi.org/10.1016/j.compedu.2018.07.021

Allen, J. M., Vahid, F., Downey, K., & Edgcomb, A. D. (2018). Weekly programs in a CS1 class: Experiences with auto-graded many-small programs (MSP). *ASEE Annual Conference and Exposition, Conference Proceedings*, *2018-June*. https://doi.org/10.18260/1-2--31231

Ashenafi, M. M. (2017). Peer-assessment in higher education – twenty-first century practices, challenges and the way forward. *Assessment and Evaluation in Higher Education*, *42*(2), 226–251. https://doi.org/10.1080/02602938.2015.1100711

Barroso, L., & Morgan, J. R. (2011). Incorporating technical peer review of civil engineering student projects. *ASEE Annual Conference and Exposition, Conference Proceedings*. https://doi.org/10.18260/1-2--18135

Biggs, J. B., & Tang, C. (2007). *Teaching for Quality Learning at University*. Open University Press/McGraw-Hill Education.

Bishop, J. L., & Verleger, M. A. (2013). The flipped classroom: A survey of the research. *ASEE Annual Conference and Exposition, Conference Proceedings*, *August*. https://doi.org/10.18260/1-2--22585

Colbert, V., & Arboleda, J. (2016). Bringing a student-centered participatory pedagogy to scale in Colombia. *Journal of Educational Change*, *17*(4), 385–410. https://doi.org/10.1007/s10833-016-9283-7

Cruickshank, H., & Fenner, R. (2012). Exploring key sustainable development themes through learning activities. *International Journal of Sustainability in Higher Education*, *13*(3), 249–262. https://doi.org/10.1108/14676371211242562

Davidson, J., Prahalad, V., & Harwood, A. (2021). Design precepts for online experiential learning programs to address wicked sustainability problems. *Journal of Geography in Higher Education*, *45*(3), 319–341. https://doi.org/10.1080/03098265.2020.1849061

EOP. (2020). *The Engineering for One Planet Framework: Essential Learning Outcomes for Engineering Education*.

Filius, R. M., de Kleijn, R. A. M., Uijl, S. G., Prins, F. J., van Rijen, H. V. M., & Grobbee, D. E. (2018). Strengthening dialogic peer feedback aiming for deep learning in SPOCs. *Computers and Education*, *125*(June), 86–100. https://doi.org/10.1016/j.compedu.2018.06.004

Gilboy, M. B., Heinerichs, S., & Pazzaglia, G. (2015). Enhancing student engagement using the flipped classroom. *Journal of Nutrition Education and Behavior*, *47*(1), 109–114. https://doi.org/10.1016/j.jneb.2014.08.008

Guo, P., Saab, N., Post, L. S., & Admiraal, W. (2020). A review of project-based learning in higher education: Student outcomes and measures. *International Journal of Educational Research*, *102*(May), 101586. https://doi.org/10.1016/j.ijer.2020.101586

Haan, G. de. (2010). The development of ESD-related competencies in supportive institutional frameworks. *International Review of Education Volume*, *56*(2–3), 315–328.

Han, E., & Klein, K. C. (2019). Pre-class learning methods for flipped classrooms. *American Journal of Pharmaceutical Education*, *83*(1), 40–49. https://doi.org/10.5688/ajpe6922

Hempel, B., Kiehlbaugh, K., & Blowers, P. (2020). Scalable and Practical Teaching Practices Faculty Can Deploy to Increase Retention: A Faculty Cookbook for Increasing Student Success. *Education for Chemical Engineers*, *33*, 45–65. https://doi.org/10.1016/j.ece.2020.07.004

Jones, L. (2007). *The Student-Centered Classroom*. Cambridge University Press.

Jovanovic, J., Mirriahi, N., Gašević, D., Dawson, S., & Pardo, A. (2019). Predictive power of regularity of pre-class activities in a flipped classroom. *Computers and Education*, *134*(February), 156–168. https://doi.org/10.1016/j.compedu.2019.02.011

Jupyter, P., Blank, D., Bourgin, D., Brown, A., Bussonnier, M., Frederic, J., Granger, B., Griffiths, T., Hamrick, J., Kelley, K., Pacer, M., Page, L., Pérez, F., Ragan-Kelley, B., Suchow, J., & Willing, C. (2019). nbgrader: A Tool for Creating and Grading Assignments in the Jupyter Notebook. *Journal of Open Source Education*, *2*(11), 32. https://doi.org/10.21105/jose.00032

Kim, M. K., Kim, S. M., Khera, O., & Getman, J. (2014). The experience of three flipped classrooms in an urban university: An exploration of design principles. *Internet and Higher Education*, *22*, 37–50. https://doi.org/10.1016/j.iheduc.2014.04.003

Lehmann, M., Christensen, P., Du, X., & Thrane, M. (2008). Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education. *European Journal of Engineering Education*, *33*(3), 283–295. https://doi.org/10.1080/03043790802088566

Lozano, R., Merrill, M. Y., Sammalisto, K., Ceulemans, K., & Lozano, F. J. (2017). Connecting competences and pedagogical approaches for sustainable development in higher education: A literature review and framework proposal. *Sustainability (Switzerland)*, *9*(10), 1–15. https://doi.org/10.3390/su9101889

Malmqvist, J., Edström, K., & Rosén, A. (2020). UPDATES TO THE CORE CDIO STANDARDS. *Proceedings of the 16th International CDIO Conference, Hosted on-Line by Chalmers University of Technology, Gothenburg, Sweden, 8-10 June 2020*.

Malmqvist, J., Edström, K., Rosén, A., Hugo, R., & Campbell, D. (2020). A First Set of Optional CDIO Standards for Adoption. *Proceedings of the 16th International CDIO Conference, Hosted on-Line by Chalmers University of Technology, Gothenburg, Sweden, June 8–11, 2020*.

Malmqvist, J., Lundqvist, U., Rosén, A., Edström, K., Gupta, R., Leong, H., Cheah, S. M., Bennedsen, J., Hugo, R., Kamp, A., Leifler, O., Gunnarsson, S., Roslöf, J., & Spooner, D. (2022). The CDIO Syllabus 3.0 - an Updated Statement of Goals. *Proceedings of the 18th International CDIO Conference, Hosted by Reykjavik University, Reykjavik Iceland, June 13-15, 2022.*, 18–36.

Reeves, T. C. (2006). How do you know they are learning? The importance of alignment in higher education. *International Journal of Learning Technology*, *2*(4), 294. https://doi.org/10.1504/ijlt.2006.011336

Rieckmann, M. (2012). Future-oriented higher education: Which key competencies should be fostered through university teaching and learning? *Futures*, *44*(2), 127–135.

Rosén, A., Edström, K., Gumaelius, L., Högfeldt, A.-K., Grøm, A., Lyng, R., Nygaard, M., Munkebo Hussmann, P., Vigild, M., Fruergaard Astrup, T., Karvinen, M., Keskinen, M., Knutson Wedel, M., Lundqvist, U., & Malmqvist, J. (2019). Mapping the CDIO Syllabus to the UNESCO Key Competencies for Sustainability. *Mapping the CDIO Syllabus to the UNESCO Key Competencies for Sustainability, Proceedings of the 15th International CDIO Conference, Aarhus University, Aarhus, Denmark.*

Rotellar, C., & Cain, J. (2016). Research, perspectives, and recommendations on implementing the flipped classroom. *American Journal of Pharmaceutical Education*, *80*(2). https://doi.org/10.5688/ajpe80234

Segalàs, J., Ferrer-Balas, D., & Mulder, K. F. (2009). Introducing sustainable development in engineering education: Competences, pedagogy and curriculum. *SEFI 37th Annual Conference 2009*.

Steen-Utheim, A. T., & Foldnes, N. (2018). A qualitative investigation of student engagement in a flipped classroom. *Teaching in Higher Education*, *23*(3), 307–324. https://doi.org/10.1080/13562517.2017.1379481

Stöhr, C., Demazière, C., & Adawi, T. (2020). The polarizing effect of the online flipped classroom. *Computers and Education*, *147*(December 2019). https://doi.org/10.1016/j.compedu.2019.103789

UN. (2015). *Transforming Our World: the 2030 Agenda for Sustainable Development United Nations United Nations Transforming Our World: the 2030 Agenda for Sustainable*.

Unesco. (2017). *Education for Sustainable Development Goals – Learning Objectives* (U. Nations (ed.)).

Wiek, A., Bernstein, M., Foley, R., Cohen, M., Forrest, N., Kuzdas, C., Kay, B., & Withycombe, K. L. (2016). Operationalising competencies in higher education for sustainable development. In *Handbook of Higher Education for Sustainable Development* (pp. 241–260). Routledge.

Wiek, A., Withycombe, L., & Redman, C. . (2011). Key competencies in sustainability: A reference framework for academic program development. *Sustainability Science*, *6*(2), 203–218.

Wright, G. B. (2011). Student-Centered Learning in Higher Education. *International Journal of Teaching and Learning in Higher Education*, *23*(3), 92–97.

BIOGRAPHICAL INFORMATION

Johan Berg Pettersen is Associate Professor at the Industrial Ecology Programme and Dept. of Energy and Process Engineering at NTNU. He is study program manager and Head of studies in Energy and Sustainability at the Faculty of Engineering. He teaches undergrad and graduate courses in sustainable engineering and applied sustainability assessment. His research interest is circular and life cycle engineering of production and consumption systems.

Ulrika Lundqvist is Professor at Chalmers University of Technology in Sweden. She is part of Chalmers' executive committee for education as Dean of education for lifelong learning. Her research is within Industrial Ecology, focusing on criteria, indicators, and backcasting for sustainable development, as well as within education for sustainable development in higher education, focusing on quality issues and change processes.

Corresponding author

Johan Berg Pettersen
NTNU Norwegian University of Science and Technology
Industrial Ecology Programme, Dept. of Energy and Process Engineering
Realfagbygget E4, Høgskoleringen 5
7491 Trondheim, NORWAY
(+47) 93 80 90 82
johan.berg.pettersen@ntnu.no