


OPINION ARTICLE

Experiences and perspectives regarding challenge-based learning in online sustainability education [version 1; peer review: 2 approved, 2 approved with reservations]

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Abstract

In this opinion article, the authors share their experiences with and perspectives on course design requirements and barriers when applying challenge-based learning (CBL) in an online sustainability education setting. CBL is an established learning approach for (higher) sustainability education. It enables teachers to engage students with open, real-life grand challenges through inter-/transdisciplinary student team collaboration. However, empirical research is scarce and mainly based on face-to-face CBL case studies. Thus far, the opportunities to apply CBL in online educational settings are also underinvestigated.

Using the TPACK framework, the authors address technological, pedagogical and content knowledge related to CBL and online sustainability education. The integration of the different components is discussed, providing teachers and course designers insight into design requirements and barriers.

This paper supports the promising future of online CBL for sustainability education, especially in the context of inter-/national inter-university collaboration, yet emphasizes the need for deliberate use of online collaboration and teaching tools.


Keywords


challenge-based learning, online learning, online challenge-based learning, online sustainability education, TPACK, transactional distance, community of inquiry

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Introduction

Addressing complex sustainability issues in higher education requires the combination and integration of various disciplines, perspectives, and approaches. Universities are playing an important role in preparing students to “take a critical stand on disciplinary limitations, solving complex problems across disciplines, communicating across disciplines, handling interdisciplinary collaboration and teamwork, as well as using integrative potentials to create innovations” (Brassler & Dettmers, 2017, p.2; Lattuca *et al.*, 2012; Pecukonis *et al.*, 2008; Shen *et al.*, 2015). Transversal skills like collaboration, critical thinking, persistence, and problem solving are needed to succeed in a world faced by global challenges (Gallagher & Savage, 2020; Monterrey, 2015; Portuguese Castro & Gomez Zermeno, 2020).

Several educational programs, mostly STEM (science, technology, engineering and mathematics) curricula, prepare students to deal with real-life complex challenges. These courses are often based on a challenge-based learning (CBL) approach. CBL is an active learning approach in which students gain skills and knowledge through active engagement with an urgent real-life challenge, and collaborative work on creative and sustainable solutions (Bohm *et al.*, 2020; Chicharro *et al.*, 2019; Ettema *et al.*, 2020; Gallagher & Savage, 2020; Malmqvist *et al.*, 2015; Martin & Bolliger, 2018; van den Beemt *et al.*, 2020; Vreman-de Olde *et al.*, 2021).

In 2008, Nichols and Cator published a CBL guide and framework to support educational institutions in engaging their students in real-life, complex problems and meeting the needs of 21st century workplace skills (Nichols *et al.*, 2016). Although the term ‘CBL’ is still rather new, the concept of exposing students to real-life problems, requiring collaboration and development of solutions has been applied for many years in the engineering and sustainable development field (Bootsma *et al.*, 2014; Jou *et al.*, 2010). Hackathons and engineering contests also known as Challenge-Based Innovation (CBI) projects can be seen as CBL in an earlier form (Colombari *et al.*, 2021; Jou *et al.*, 2010).

In the Netherlands, for example, several CBL courses have been co-developed within a strategic alliance between three universities: Utrecht University, Eindhoven University of Technology and Wageningen University & Research (<https://www.uu.nl/en/collaborate/utrecht-eindhoven-wageningen-alliance>). An interdisciplinary and inter-university teacher team developed the ‘Inter-University Sustainability Challenge’ as part of this alliance. Open to all bachelor programs, this 10-week online bachelor course enabled students to collaboratively work on solutions for sustainable cities, following a CBL approach.

The lack of empirical research on (online) CBL, motivated us to conduct qualitative and quantitative research in the first and second course run to understand the influence of online CBL on student perceptions (Kasch *et al.*, in review). At the time of writing this paper, data collection and analysis of the second course run was ongoing. Developing and researching this innovative way of online CBL in a higher education sustainability course inspired us to share our experiences.

Aim of this paper

In this paper, we addressed CBL in an online sustainability course from three basic knowledge types: pedagogical, content and technological. We share our perspectives on the requirements and barriers that teachers and course designers will encounter, especially when it comes to inter-/transdisciplinary interaction and collaboration in an online setting between different universities. Sharing our perspectives of online CBL in sustainability education, we shed light on theoretical and practical requirements and barriers that should be taken into account prior to course design.

Considerations of Technological Pedagogical Content Knowledge (TPACK)

In this paper we use the TPACK framework (Koehler & Mishra, 2009) as a lens to look at the different knowledge types required when designing a challenge-based, online sustainability bachelor course. The framework focuses on technological, pedagogical and content knowledge which all play an important role in the design of an online CBL course. Effective technology use in a curriculum setting requires knowledge about the complex and dynamic relationship between these three knowledge types (Falloon, 2011; Koehler & Mishra, 2009; Ward & Benzoni, 2010). Their integration will enable teachers to create satisfying learning experiences for their students (Álvarez-Otero & de Lázaro y Torres, 2018).

Addressing requirements and barriers of online CBL in sustainability education, we will first focus on each main knowledge type separately: pedagogy, content, and technology after which we will address their integration.

Pedagogical knowledge: challenge-based learning

Koehler and Mishra (2009) describe pedagogical knowledge as generic knowledge and experience about teaching and learning methods, assessment and classroom management (Koehler & Mishra, 2009). In the context of this paper, teachers/course designers will require knowledge about CBL as an approach for teaching and learning.

It is interesting to note that a commonly agreed definition and framework of CBL is lacking. Different authors use slightly different definitions for CBL and thus increase the fluidity of this approach (Gallagher & Savage, 2020). Nichols and Cator (2008) who also developed a well-known CBL framework (<https://www.challengebasedlearning.org/framework/>) provide the following definition:

“Challenge Based Learning is an engaging multidisciplinary approach to teaching and learning that encourages students to leverage the technology they use in their daily lives to solve real-world problems. Challenge Based Learning is collaborative and hands on, asking students to work with peers, teachers, and experts in their communities and around the world to ask good questions, develop deeper subject area knowledge, accept and solve challenges, take action, and share their experience.”

Next to its fluid definition there is no agreement on the predecessors of CBL (Gallagher & Savage, 2020). Some state that CBL is

grounded in the longstanding constructivist "experiential learning" theory (Johnson *et al.*, 2009; Monterrey, 2015; Nichols *et al.*, 2016; Portuguese Castro & Gómez Zermeño, 2020; Vreman-de Olde *et al.*, 2021). After examining 100 publications on CBL, Gallagher and Savage (2020) concluded that different approaches and frameworks of CBL are used, using the term "CBL" in different ways and thus making it confusing for teachers and researchers to understand what CBL is and how it can be implemented (Gallagher & Savage, 2020).

A CBL framework was developed (Nichols & Cator, 2008) which is widely used in the literature consisting of three interconnected phases students are going through: Engage, Investigate and Act (<https://www.challengebasedlearning.org/framework/>). We used their framework and created a new visualization (Figure 1) that helps teachers and students to understand the different actions that are related to the CBL framework and its three phases. The double diamond (Figure 1) shows the iterative character of a CBL process.

Engage: from essential questions to defining focus. Starting from a "big idea", an open-ended, real-life challenge (e.g., global warming, poverty, pandemic), interdisciplinary student teams start working towards a challenge solution (Nichols & Cator, 2008). A challenge can be presented by teachers, external stakeholders or chosen by the students themselves. Working on complex, real-life challenges is inherently challenging and will require students to break down the content into more manageable pieces. After becoming familiar with the challenge at hand, students gradually move from a big abstract idea to a specific, actionable challenge question. They work in a highly self-regulated way and gain new knowledge and link theory to practice by actively engaging with the challenge rather than passively consuming lectures and reading materials (Johnson *et al.*, 2009).

Due to the openness and complexity of real-life challenges, students can temporarily lose focus and feel uncertain during their (Pearce *et al.*, 2018). Teachers therefore have a facilitating role and co-learn, facilitate, evaluate, and coach their investigation and inquiry process. Coaches are non-directive yet supportive and engage students in critical thinking and reflection as well as support inter-transdisciplinary collaboration (Johnson *et al.*, 2009; Pearce *et al.*, 2018). Effective coaches let go of control, trust the process and allow students freedom

of choice (Kirkels *et al.*, 2002; Savin-Baden, 2014). A coach has problem-solving skills and shows openness and flexibility towards new approaches and perspectives (Johnson *et al.*, 2009; Nichols *et al.*, 2016). As an unexperienced coach, it might take time to adjust to the new role and training to become a facilitator. Teachers might need time to adjust and revise their assumptions on what it entails to be a coach in CBL, what students should learn and how.

Investigate: data collection and analysis. After exploring the challenge students choose the research/design questions they want to investigate. Within their team they define the scope of their approach, the knowledge and skills needed, collect data and integrate different perspectives with a critical, reflective mindset (Johnson *et al.*, 2009; Martin & Bolliger, 2018; Nichols *et al.*, 2016; Vreman-de Olde *et al.*, 2021). As mentioned above, teachers should monitor/guide the student teams' progress.

The goal of this iterative phase is to inform the next and last CBL phase.

Act: development of (concept) solution. CBL concludes with the development, testing of evidence-based prototypes of the challenge followed by implementation in an authentic environment (Nichols *et al.*, 2016). The possibilities for actual testing and implementation highly depend on the available time and resources within a course context (Nichols *et al.*, 2016).

Content knowledge – sustainability education

The grand sustainability challenges that the world is currently facing, like climate change and feeding the world's population cannot be solved by one discipline and have to be tackled at the interface of different disciplines, including natural sciences, social sciences and humanities (Bootsma *et al.*, 2014; Frisk & Larson, 2011). Where sustainability education started out more as a natural sciences oriented environmental education, it has evolved to an interdisciplinary approach in "education for sustainable development", and more recently to a transdisciplinary approach in "education for a sustainable future" (O'Brien *et al.*, 2013). Inter- and transdisciplinarity are core concepts in sustainability education which can provide students the opportunity to address complex, real-world problems (Bootsma *et al.*, 2014; Di Giulio & Defila, 2017). Interdisciplinarity as defined by Tress *et al.* (2005) are "studies that involve several unrelated academic disciplines in a way that forces them to

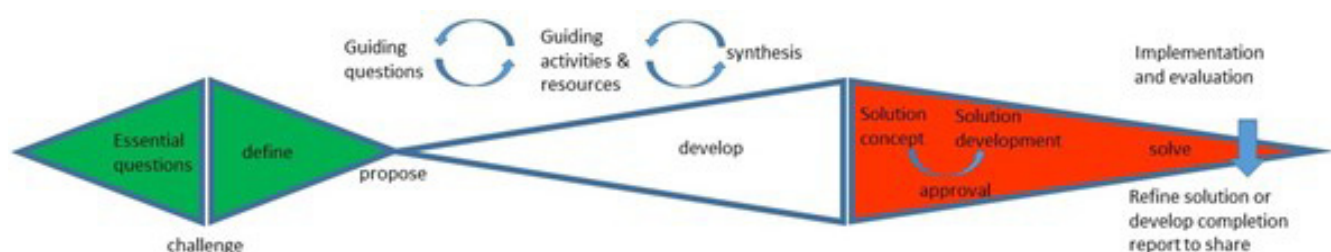


Figure 1. CBL Double-Diamond: Structure of a CBL course with the three CBL phases: Engage/explore, investigate/analyze and Act/developing solutions. Although the phases are presented as consecutive, in reality the project will be an iterative process. Own figure, adapted from British Design Council (2005).

cross-subject boundaries to create new knowledge and solve a common research goal.” (p. 179). Going a step further, transdisciplinarity can be described as “studies that both integrate academic researchers from different disciplines with non-academic participants, such as land managers and the public, to create new knowledge and research a common goal.” (Tress *et al.*, p. 179). An important argument in favor of transdisciplinary collaboration and co-production of knowledge is that non-academic participants are often more aware of and familiar with the level of complexity than academic scholars (Abson *et al.*, 2017). It is therefore important that students are trained, get exposed to real life challenges and collaborate with societal partners that are working on sustainability challenges (O’Brien *et al.*, 2013).

The inter- and transdisciplinary character of sustainability issues can only be addressed through a systems approach (Sverdrup, 2019) which is thus seen as a relevant competency of students studying sustainability education (Frisk & Larson, 2011). This includes an inter- and transdisciplinary approach, systems analysis, and resilience thinking (Fazey *et al.*, 2007), as well as building the student’s ability for critical and reflective thinking (Howlett *et al.*, 2016).

Technological knowledge - online education

Teachers’ attitude and skills towards online education and technology shape students’ online learning experience (Castro & Tumibay, 2021). Likewise, students’ preference for and experience with online learning can influence their perceptions and engagement with an online course (Huang *et al.*, 2016). Implementing technology into higher education and developing an online course requires not only an openness towards technological tools but also knowledge of when a certain technology can assist or impede the educational objective (Koehler & Mishra, 2009). Since there is no one-size fits all solution to online education, teachers will need the space to experiment and continuously develop their technological knowledge.

New technologies are emerging fast, especially during the COVID-19 pandemic which forced most of the higher education to practice ‘online only’ education. In just a few days teachers had to shift from regular to online/remote teaching. Although this type of emergency online courses should not be compared to “regular” online courses, it provided teachers and researchers insight in the possibilities of online learning. Despite experiencing difficulties in online learning and collaboration, the pandemic has shown us the benefits and forced teachers who otherwise would not have explored online possibilities to become creative. It has shown us the huge benefits of online education in times of crisis (Dhawan, 2020).

Looking at interaction in online education, online student-student interaction and collaboration can take place synchronously as well as asynchronously. Synchronous online interaction requires teachers as well as students interacting in real time whilst being at different locations. Virtual classrooms, live streams, online presentations, online office hours as well as collaborative writing tools such as google docs can be used for synchronous online interaction (Andrade, 2012; Schullo, 2005). Research has shown that

synchronous interaction positively affects students’ perceptions of belonging, connectedness, social interaction, expression, and cognitive processes (McBrien *et al.*, 2009; Peterson, 2019).

Asynchronous interaction is used for instruction that does not require real-time/simultaneous engagement. Examples are pre-recorded videos, email, and discussion boards (Andrade, 2012; Schullo, 2005). It allows both students and teachers time to think about their response. Applications such as Microsoft Teams and their “Office 365 Education” plan offered new possibilities for synchronous and asynchronous online education (Pal & Vanijja, 2020). Compared to already existing platforms such as Moodle and Blackboard, formerly business communication platforms such as MS Teams and Zoom provide an online teaching-learning space that enable real time interaction, video conferencing, file sharing, recording, chat, and group work (Pal & Vanijja, 2020).

Depending on students’ prior experience with online learning and the level of required autonomy students might struggle in an online environment since it requires more self-regulation for example when being tasked to schedule their own time for learning (Andrade, 2012). Students’ interdisciplinary collaboration skills and preferences might influence adjustment time to this type of teaching and learning. For a highly collaborative and demanding online course to be effective, expectation management is needed to prepare students for an active, student-centered and student-lead learning experience (Andrade, 2012).

Online challenge-based sustainability education

Successful online challenge-based sustainability education depends on the deliberate integration of pedagogy, content, and technology. However, expert knowledge of one or all aspects will not automatically lead to a coherent course design. Sustainability education teachers and course designers should therefore be aware of the requirements and barriers related to the integration of CBL (pedagogy), sustainability education (content) and online learning (technology). In this section we again use the TPACK framework as a lens to address requirements and barriers of online CB sustainability education, this time focussing on the integration of the pedagogy, content and technology.

Pedagogical content knowledge (PCK) – CBL sustainability education

CBL allows for multi-, inter-, as well as transdisciplinary collaboration (Nichols *et al.*, 2016; Vreman-de Olde *et al.*, 2021) and is said to foster students’ ability to work in inter-transdisciplinary teams and support the acquisition of a range of 21st century skills such as self-awareness, decision making, problem solving, teamwork, entrepreneurial mindset, and communication skills (Johnson *et al.*, 2009; Kohn Radberg *et al.*, 2020). Additionally, CBL is said to offer universities a framework to create learning environments that bridge theory with practice by engaging students with urgent, real-life societal challenges (Bohm *et al.*, 2020; Bootsma *et al.*, 2014; Kohn Radberg *et al.*, 2020; Nichols *et al.*, 2016). The literature provides examples of transdisciplinary CBL involving students, teachers and external stakeholders however, less is known about the input and role of external stakeholders (Gallagher & Savage, 2020;

Santos *et al.*, 2015). Collaboration with external partners/stakeholders such as peers and experts (entrepreneurs, citizens, local actors) plays an important part in CBL (Bombaerts, 2020; Nichols & Cator, 2008). It can have added value for students provided that the stakeholder is available for student questions and sincerely interested in their solutions (Bootsma *et al.*, 2014). External stakeholders can also call on students. When working with societal stakeholders, students can get insight into societal needs and gain new perspectives, and authentic experiences outside of their classroom (Bootsma *et al.*, 2014).

The relevance of CBL for higher sustainability education is supported by the literature and in line with our own experience. We developed both an interdisciplinary as well as transdisciplinary online CBL course and found that engagement with an external stakeholder who proposes a challenge question does add value. Students feel that their work and opinions matter and that they can contribute to something real. However, we don't see external stakeholder involvement as prerequisite since it has to fit into the timeframe of a course. Independent of external parties' involvement, we highly encourage interdisciplinary and inter-university teaching teams co-developing and teaching (online) CBL courses. This will allow teachers to cater for a rich variety of prior knowledge and skills as well as students learning experiences (Malmqvist *et al.*, 2015).

Key competences and approaches for sustainability education are among others, systems thinking, long-term and critical thinking, collaboration, engagement, and action orientation (Frisk & Larson, 2011; Lozano *et al.*, 2019). Students need to understand the different systems involved and their relationship to each other (Green *et al.*, 2022; Redman & Larson, 2011). Systems thinking has also been successfully used in problem-based (PBL) and project-based learning (PjBL) (Nagarajan & Overton, 2019).

We experienced that systems thinking can play an important role during the first and second phase of a CBL cycle where students are engaging and investigating a challenge from various perspectives and disciplines. CBL can support students' systems thinking and exploration of the interconnectedness between systems.

Technological content knowledge (TCK) – online sustainability education

Benefits of online learning for sustainability education relate to the possibilities for intercultural perspectives, interdisciplinary communication, and knowledge generation as well as project management (Barth & Burandt, 2013). Additionally, international collaboration can strengthen the development of creative solutions for global challenges (Wiek *et al.*, 2014). It allows for greater geographical and educational flexibility as well as accessibility.

At the same time, online learning requires students to take active ownership of their learning which might be new to some students (Andrade, 2012). Course design elements such as learning goals, activities and deadlines should be clearly defined in an

online course environment since students and teachers have less opportunities to ask clarifying questions (Andrade, 2012; Huang *et al.*, 2016).

Online learning (tools), such as simulation-based learning environments, are suitable for engaging students with sustainability issues (Green *et al.*, 2022). System dynamic simulations support students practical understanding of sustainability as well as enable student to build a simulation and/or use and experiment with an existing one (Green *et al.*, 2022). The benefit of online learning tools and materials is that they allow students to modify them to their needs, focus and discipline and thus making use of them in their own way (Jung, 2001). Online, students can be supported through formative feedback, especially when provided through live online videos which give students the chance to discuss and elaborate on the feedback increasing its value (Yilmaz & Yilmaz, 2020).

Depending on the challenge topic, an online CBL course can engage students with a real-life challenge and expose them to other disciplines, yet the actual testing and development of proposed challenge solutions is limited. In our 10 weeks online CBL courses we experienced that the theoretical development of a challenge solution for example a visualization of a prototype is feasible, whereas the actual development and testing of a physical prototype is out of scope and more difficult to facilitate online. Visualization programs such as Tygron and Minecraft have been interesting tools offering students various possibilities to become creative and collaborate online. For an overview of various requirements and barriers related to online CBL see Table 1. Although not exhaustive, this table is based on the authors online CBL teaching experiences.

Technological pedagogical knowledge (TPK) – online CBL

The relevance and possibilities of technology for CBL has been pointed out by the authors of the CBL framework and learning guide (Nichols & Cator, 2008; Nichols *et al.*, 2016). Technology plays an essential role during for example researching, analysing, collaboration and communication (Nichols *et al.*, 2016). Technological tools can enhance students' ownership of their learning process and allow teachers to expand their classroom (Nichols *et al.*, 2016). Additionally, it enables students to creatively engage and visualize innovative sustainable solutions.

The majority of CBL studies focus on face-to-face education (Bohm *et al.*, 2020; Ettema *et al.*, 2020; Kohn Rådberg *et al.*, 2020; Malmqvist *et al.*, 2015; Santos *et al.*, 2015). Portuguese Castro & Gómez Zermeño (2020) share promising results of a case study conducted in an online, CBL, higher education course on the sustainable development goals (SDGs) in Mexico. Their online course promoted students' interest in SDGs and supported the acquisition of transversal skills related to multidisciplinary collaboration. The online setting provided the interdisciplinary student teams more flexibility to communicate and collaborate at different times and places. In the future, we expect more online CBL courses or projects enabling inter-university collaboration.

Table 1. Requirements and barriers for online CBL courses.

TPACK knowledge		Requirements of online CBL	Barriers toCBL	Barriers to Online Learning
Pedagogy	Safe & open course setting	<ul style="list-style-type: none"> - Feeling safe, comfortable, confident 	<ul style="list-style-type: none"> - Lack of openness towards other disciplines, approaches, scientific methods 	<ul style="list-style-type: none"> - Asked to turn on camera
	Student autonomy	<ul style="list-style-type: none"> - Student driven: learning activities, data collection, collaboration activities - Motivation - Self-regulation 	<ul style="list-style-type: none"> - Lack of self-regulated learning skills especially in different years/ levels? - Joint team planning - Planning team meetings (especially between students from different study programs and/or universities) 	<ul style="list-style-type: none"> - Lack of self-regulated learning skills - No social control about partial products – no trust? - Joint team planning depends on individual competing tasks – courses <p>Muilenburg & Berge (2005):</p> <ul style="list-style-type: none"> - Preference for in-person learning - Procrastination - Lack of motivation
	Teacher role	<ul style="list-style-type: none"> - Coach support - Teacher = facilitator - Online teaching/coaching skills - High time investment prior to the course e.g. online course set-up 	<ul style="list-style-type: none"> - Lack of coaches - Low coaching skills 	<p>Muilenburg & Berge (2005):</p> <ul style="list-style-type: none"> - Accessibility teacher - Lack of online teaching skills - Lack of timely feedback & support - high student-teacher ration
	(Interdisciplinary) collaboration	<ul style="list-style-type: none"> - Openness for other disciplines/approaches - Intensive group work/ collaboration - High student engagement - Interdisciplinary communication/jargon - Social interaction 	<ul style="list-style-type: none"> - Lack of basic inter-transdisciplinary skills - Low group work/collaboration skills - Low awareness of team roles and the potential of communication about team roles' flexibility - Freeriding of team members - Low communication skills - Lack of social interaction - Lack of interdisciplinarity within a student team 	<p>Muilenburg & Berge (2005):</p> <ul style="list-style-type: none"> - Lack of student-student interaction & collaboration - Impersonal learning - Feeling isolated - Lack social context cues - Low student engagement
	Academic skills	<ul style="list-style-type: none"> - Students' design thinking skills - Self-regulation skills - Reading, writing, communication skills at the approximately same level 	<ul style="list-style-type: none"> - Lack of design thinking skills 	<ul style="list-style-type: none"> - Low accessibility to visually impaired - Low online collaboration skills <p>Muilenburg & Berge (2005):</p> <ul style="list-style-type: none"> - Lack pf language, reading, writing, communication skills for online learning
Content	Student autonomy	<ul style="list-style-type: none"> - Freedom in challenge solution - Contacting external stakeholders (if applicable) 	<ul style="list-style-type: none"> - Finding/formulating a joint challenge topic 	
	Authentic learning content	<ul style="list-style-type: none"> - Real challenges - Teacher prepares online learning materials 	<ul style="list-style-type: none"> - No Intrinsic interest in topic [S] - danger of exit behaviour when other topic was chosen by the group? 	<ul style="list-style-type: none"> - Low quality learning materials - Low quality VR teaching - Being aware of large diversity in student needs
	Complex challenges		<ul style="list-style-type: none"> - Getting lost in exploration - Development and implementation of evidence based solutions 	<ul style="list-style-type: none"> - Low learning enjoyment [S]

Technology	Online communication and interaction	<ul style="list-style-type: none"> - Accessibility of communication tools to all students & teachers - Usability of tools - Technical support - Spaces for blended / online teaching and collaboration - Scalable synchronous interaction, lectures - Asynchronous interaction/ teaching through for example recordings - Internet connection 	<ul style="list-style-type: none"> - Poor internet connection 	<ul style="list-style-type: none"> - Lack of technical support Mullenburg & Berge (2005); - Fear of new tools and technology - Lack of online skills - Poor internet connection
	Technology follows pedagogy	<ul style="list-style-type: none"> - Intentional integration of technology 	<ul style="list-style-type: none"> - Lack of collaboration spaces 	<ul style="list-style-type: none"> - Limited online collaboration facilities
	Visualisation skills	<ul style="list-style-type: none"> - Design tools - Design skills (our context) 		

Additionally, looking back at the COVID-19 pandemic, we see how it has deeply affected (higher) education which is why exploring and addressing the possibilities of CBL in an online course setting is promising and should be further explored ([Colombari et al., 2021](#); [Dhawan, 2020](#)). Developing and teaching two online CBL courses has shown as the following requirements and barriers of online CBL in sustainability education.

General requirements for (online) CBL. CBL can provide students with several active learning opportunities in the form of collaborative group work, discussion, integration, and reflection. Inter-/transdisciplinary collaboration will expose students to other disciplines, their perspectives and approaches. They will approach sustainability issues from a broader perspective enabling them to account for more aspects compared to monodisciplinary student teams.

A CBL course is not highly structured in a sense that it does not prescribe students what to do and how to solve a challenge. This dynamic course process puts new demands on students, teachers and course designers ([Malmqvist et al., 2015](#)). Students as well as teachers have to be flexible when working in an interdisciplinary context on open, complex real-life challenges. It requires students to be collaborative as well as autonomous. They have to plan and schedule their team meetings, set internal deadlines and hold each other accountable for their work. It requires working around each other's schedules (especially in an inter-university setting) and handling external factors such as deadlines of parallel courses. Internal communication and planning become even more relevant in an online setting. Teachers, supporting students as coaches will have to tailor their feedback to student teams needs and will be less able to provide subject related (expert) feedback ([Malmqvist et al., 2015](#)). It has been pointed out that students might experience this as lack of support ([Malmqvist et al., 2015](#)) which confirms that students should be aware of what CBL entails and requires.

In an online CBL course, integrating technological and pedagogical knowledge is especially interesting, since CBL and

online learning have requirements and barriers, some of which are overlapping. Many requirements and barriers to effective collaboration are common in face-to-face as well as online learning ([Hughes et al., 2002](#)). However, some barriers can be more prevalent in an online course setting that is based on interdisciplinary group work between new people from other disciplines in a flexible and open learning experiences such as CBL.

Online supports inter-/transdisciplinary collaboration. Applying CBL in an online setting enables inter-/transdisciplinary collaboration on real-life sustainability challenges, especially for inter-university collaboration. It allows for more accessibility, reaching high student numbers and enables collaboration at distance on an inter-/national level.

We co-developed an online CBL sustainability course between teachers from three Dutch universities. Online collaboration enabled teachers to meet more frequently which would not have been feasible to do face to face. However, it took teachers more time to get to know each other and find a common language.

Students had similar experiences. While online CBL offers more flexibility and autonomy about their learning process, communicating online with strangers from different disciplines, meeting regularly does take more effort. However, students do understand the benefits and need of an online course format when it comes to inter-/transdisciplinary collaboration, especially in an international context.

Community of inquiry in online CBL. CBL is heavily based on student collaboration. From the literature we know that online collaboration aiming for new knowledge construction requires students to form a "Community of Inquiry" (CoI) in which they collaboratively work towards a goal and learn with and from each other ([Garrison & Cleveland-Innes, 2005](#)). In a CoI, students feel connected to their learning community, build trust, support each other, and feel a mutual benefit from collaborating with each other ([Rovai, 2000](#)). Course design and pedagogy matter most when it comes to acquiring a sense of community in

online learning (Rovai, 2000). Since CoI's are not formed by themselves they require teachers to support and enhance feelings of presence and community.

Cognitive, social and teaching presence are needed for deep learning and inquiry within a CoI (Garrison & Cleveland-Innes, 2005). Interactive synchronous online sessions can support online presence and a sense of community (Martin & Bolliger, 2018). Personal contact *e.g.*, through making eye contact, addressing students by their name, or offering Q&A sessions enhances online interactiveness and presence (Martin & Bolliger, 2018). Research has shown that online teacher presence increases student engagement. Important strategies for teachers to engage students online are guided questions and prompts to deepen students understanding of the content (Martin & Bolliger, 2018). Regular announcements and reminders are highly valued by students and increase engagement, too.

We see a clear link between the CoI concept and inter-/transdisciplinary collaboration in the context of an online CBL course. The formation of a CoI consisting of students, teachers and, if applicable, external stakeholders is needed for successful online collaboration on open, complex challenges. Our research has shown that moderately high levels of CoI can be acquired in an online, inter-university CBL setting when using rich synchronous and asynchronous interaction tools (Kasch *et al.*, in review). Online courses that emphasize synchronous video-based learning and teaching can increase just-in-time feedback, feelings of social presence, enable collaboration and deep learning. In a CBL course, student teams require personal coaching and feedback since general feedback is less suitable due to the different focus, topics and background of the student teams. This makes online feedback in a CBL setting less scalable. Therefore, online CBL courses with high student numbers teams require more time investment per coach or more coaches. Online coaching sessions or check-ins can increase students' sense of shared responsibility. Metacognitive support and reflection questions can support learning and their teams progress (Yilmaz & Keser, 2017). Coaches can provide support student bonding and recognizing each other's strengths, emphasizing that every team member is needed and valued. If necessary, student engagement can be assessed in a summative way based on the quantity and quality of their contribution (Rovai, 2000). Coaching can also focus on setting goals, committing to certain choices, trusting each other and the process and managing the information resources available (Nichols *et al.*, 2016).

Interaction and transactional distance in online CBL. High student engagement is essential for online collaboration (Martin & Bolliger, 2018) and thus online CBL. Research shows that high student engagement is related to low perceptions of transactional distance (Bolliger & Halupa, 2018). Transactional distance is a personal perception of the psychological space between students, teachers, and the course content relevant to both face-to-face as well as online learning (Moore, 2013). Fostering and sustaining interaction online is important, yet difficult to achieve (Jung, 2001; Yilmaz & Yilmaz, 2020). Successful collaboration and inquiry (CoI) requires successful

student–student, student–content and student–teacher interaction. Additionally, CBL is characterized by interdisciplinary student teams with cultural and social differences which can result in high levels of transactional distance (Bolliger & Halupa, 2018).

The quantity and quality of online dialogue and interaction influences perceptions of "transactional distance" (Moore, 2013) as well as the sense of community among students and teachers (Rovai, 2000; Yilmaz & Yilmaz, 2020). High transactional distance can be overcome through dialogue which not only increases student understanding but also their sense of community (Moore, 2013). While no or little dialogue can lead to feelings of isolation (Rovai, 2000) and hinder the building of trust, rich video-based interaction and feedback can decrease perceptions of transactional distance (Huang *et al.*, 2016; Yilmaz & Yilmaz, 2020).

Literature on online collaboration outside of a CBL context (Chen, 2001; Huang *et al.*, 2016; Rovai, 2000; Yilmaz & Keser, 2017) supports that highly interactive online learning and synchronous video communication lead to low(er) perceptions of transactional distance which than should also apply to online CBL courses.

Our research has shown that in an online CBL course, moderately low levels of transactional distance can be achieved if teachers and course designers actively consider high levels of transactional distance (non-physical distance) as something that needs to be overcome (Kasch *et al.*, in review).

Meaningful interaction has been provided through synchronous online lectures in a virtual classroom setting as well as synchronous online coaching sessions via MS Teams (Kasch *et al.*, in review). Both tools enabled rich dialogue and exchange among students and teachers. The Virtual Classroom was experienced as the best way of online learning by students since it was able to face-to-face interaction and enable high quality video based, two-way communication. It created a sense of connectedness and students felt more engaged and motivated to participate.

The interactive polls in the Virtual Classroom motivated students to engage with the content. Being able to see the individual responses teachers could easier communicate and interact with their students despite the physical distance. Online polls and quizzes during synchronous sessions can engage students and elicit student-student, student-teacher and student-content interaction in a scalable way and increase feelings of presence and a sense of community. This type of text-based interaction opens up the floor to all students and helps online group discussions and reflection. Synchronous text-based interaction is also a convenient way to engage students who are feeling shy to speak up. Responding to online polls or quizzes does feel safer to some students. It enables engagement in group discussions without the need to raise a hand or speaking in front of more dominant peers. However, teachers inviting students individually to speak up, might raise a barrier and make students feel insecure.

During online synchronous lectures in the VC we found that students regularly had to be asked to turn on their camera. This remains a weak point for online teaching, especially in highly collaborative courses using a CBL which require visible online presence and personal interaction.

Conclusion: online challenge-based sustainability learning

We introduced CBL and showed why it is a promising approach for sustainability education. Via the TPACK framework technological, pedagogical and content knowledge for online CBL was addressed. Then we focused on the integration of technological, pedagogical and content knowledge which is needed for a successful online CBL course. As in any other (online) course, pedagogy should be leading for the choice and use of technological tools and platforms. “Technology can amplify great teaching, but great technology cannot replace poor teaching” (OECD, 2015, p.4). Regardless of the technology, it should always follow the pedagogical requirements. Putting it all together, we state that the requirements and barriers for online CBL in sustainability education are in their core related to online inter-/transdisciplinary student collaboration. In this context, the required technological, pedagogical, content knowledge (TPACK) evolves around teachers’ and course designers’ knowledge of online, inter-/transdisciplinary student collaboration. Knowledge about how to facilitate and support online interaction and collaboration is essential in CBL.

Any type of rich media that not only enables but enhances online (a)synchronous communication and collaboration is needed. Technology should be applied that enables convenient and personal two-way communication and thus bridges the psychological space (Huang *et al.*, 2016). The richer the online learning environment and online interaction, the more connected students will feel. Live sessions, workshops, stakeholder interviews and group discussions can enable online student

engagement with real-life complex sustainability challenges. Online learning platforms and tools can thus support online inter-/transdisciplinary collaboration if teachers support presence and decrease transactional distance through online dialogue and course design.

We see online CBL as a way to expand and complement face-to-face sustainability education rather than replacing it. It can provide opportunities for inter-/transdisciplinary collaboration on real-life challenges and support a student-centered approach to learning in an online learning context. The reported pedagogical benefits of CBL are promising increasing student learning motivation, active student participation and collaboration, integration of prior knowledge and skills in a multidisciplinary setting, acquisition of transversal skills such as communication, collaboration, decision making and critical thinking, developing values (Kohn Rådberg *et al.*, 2020; Malmqvist *et al.*, 2015; Portuguez Castro & Gomez Zermeño, 2020), yet empirical research is in its infancy (Gallagher & Savage, 2020).

More empirical and generalizable knowledge on the design of CBL, student learning, faculty competences, cost-effectiveness and scalability is needed (Gallagher & Savage, 2020; Malmqvist *et al.*, 2015).

Online CBL requires awareness, openness and knowledge about how technology can support pedagogy. Enthusiasm about (a)synchronous online teaching, flexibility and willingness to experiment with it are pre-requisites for successful online CBL. We encourage experimentation with simulations and other online tools through which students can engage with sustainability online.

Data availability

No data are associated with this article.

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Christian Herzog 

University of Lübeck, Lübeck, Germany

The contribution outlines challenge-based learning as a suitable method for higher sustainability education. The emphasis is particularly strong on translating the concept to online education and the challenges and potential accompanied by this. A strong point of the paper is the discussion of reducing the transactional distance when bringing the concept to the online realm.

The paper does a very good job in outlining what CBL is about, its major challenges and dynamics, as well as educators design parameters. The contribution on translating CBL into the online domain is highly valuable and several important points are raised and supported by literature.

Apart from a few typos, I recommend to index the article as is.

Is the topic of the opinion article discussed accurately in the context of the current literature?

Yes

Are all factual statements correct and adequately supported by citations?

Yes

Are arguments sufficiently supported by evidence from the published literature?

Yes

Are the conclusions drawn balanced and justified on the basis of the presented arguments?

Partly

Is the argument information presented in such a way that it can be understood by a non-academic audience?

Yes

Does the piece present solutions to actual real world challenges?

Yes

Is real-world evidence provided to support any conclusions made?

Yes

Could any solutions being offered be effectively implemented in practice?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: CBL in ethics of technology; ethics of technology, AI ethics; engineering

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 01 September 2023

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Silvia Elena Gallagher

The University of Dublin, Dublin, Ireland

I would like to thank the authors for their work on this paper. The nexus of online CBL and sustainability education is an important and timely area of research. However, I feel that the paper is lacking a focus on online CBL, and would be greatly improved if this was done. I also would recommend providing a stronger argument for online CBL at the start of the paper.

I would recommend being clearer as to whom this research would be relevant to in the 'Aims of the Paper' section. For example, instructional designers, teaching staff, educational Scientists etc. In this section I would also recommend strengthening your contribution. Currently it is "we shed light on theoretical and practical requirements and barriers that should be taken into account prior to course design." Perhaps explain why this is important, and why it is needed.

I would recommend augmenting your introduction section with more context on online CBL. You mention that there is little empirical research on this area but I would recommend expanding this section on the difference between online CBL and traditional CBL.

I would recommend augmenting the paper with more context on the TPACK model within the Considerations of Technological Pedagogical Content Knowledge (TPACK) section. Refer to other publications that have done a similar approach to other pedagogies, explain in more context why TPACK is used, its benefits, and arguments against it. What are the technological, pedagogical and content knowledge ideas contained within TPACK? Perhaps also explain why this framework

was chosen over other frameworks. This would strengthen the overall argument of the paper.

I understand why the Apple CBL model was used to frame the paper, but I suggest that the authors mention that there are many different approaches, and explain why this particular approach was selected.

In the Pedagogical Knowledge section, I feel that the discussion is more focused on explaining the different sections of CBL, rather than CBL within the TPACK model. I would like to see an improved synthesis of your findings at the end of the section.

I also feel that the 'online' element of CBL is absent in the Pedagogical Knowledge, Content Knowledge and Technical Knowledge, and could be integrated. The key point of this paper is that there is little research on online CBL, yet it is not explicitly mentioned in the first two of these sections.

I feel that Figure 1 is not the most helpful addition to this paper and could be improved by modifying it for online CBL. In its current state, I cannot see the contribution of this figure to online CBL. I would recommend redeveloping this as a framework for online CBL. This would be a good contribution. For example, a graphic integrating TPACK with CBL would be more useful (CBL (pedagogy), sustainability education (content) and online learning (technology)).

Some of the text I feel is very subjective, lacks evidence, and lacks a research basis. For example "However, we don't see external stakeholder involvement as prerequisite since it has to fit into the timeframe of a course." I think if the authors are including their perceptions, the methodology by which they did this should be included or a more explicit description of their thoughts are added.

I feel that Table 1 is a great addition to the paper, but a definition of online CBL is needed at the start of the paper to contextualize this. I feel that some sections are 'light' or confusing. For example, in the Academic Skills row, the content relates mainly to Design Thinking? A column heading is also missing. I would have liked to have seen more information as to how this table was developed.

I feel that more information on the 'Inter-University Sustainability Challenge' is needed. At this stage, the reader is unfamiliar with what happened within the challenge (although it is peppered throughout). I would suggest having a section on this for better readability.

Some of the sections require references. For example "The relevance of CBL for higher sustainability education is supported by the literature and in line with our own experience". Please insert references to support this claim.

I would like to thank the authors for their submission. However, in its current state I feel that it requires improvement and greater clarity. In particular, I feel that the focus should be on online CBL, and provide more detail on the methodological approach for their thinking.

Is the topic of the opinion article discussed accurately in the context of the current literature?

Partly

Are all factual statements correct and adequately supported by citations?

Partly

Are arguments sufficiently supported by evidence from the published literature?

Partly

Are the conclusions drawn balanced and justified on the basis of the presented arguments?

Partly

Is the argument information presented in such a way that it can be understood by a non-academic audience?

Yes

Does the piece present solutions to actual real world challenges?

Yes

Is real-world evidence provided to support any conclusions made?

Yes

Could any solutions being offered be effectively implemented in practice?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Challenge based learning, online education, sustainability education

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 01 September 2023

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Kim Flintoff 

Peter Carnley Anglican Community School, Perth, Australia

This article represents a well-researched and argued advocacy position for the adoption of challenge-based learning processes across a range of disciplines to improve both learning and action in the field of Sustainability education in online settings.

The references included and the general flow of the discussion is a very reasonable and

considered appraisal of the opportunities and evidence that exist around understanding and implementing effective strategies in online Sustainability education.

There is a good body of evidence and research in face-to-face Challenge-based strategies and this article seeks to draw insights from that area of work into the less reported online context.

The article identifies a range of possible benefits and conditions that will support the outcomes while working and learning online. The authorship team draws on a practical engagement across a collaborative project developed in the Netherlands and emphasises some key considerations in course design for CBL-supported learning in online Sustainability courses.

Is the topic of the opinion article discussed accurately in the context of the current literature?

Yes

Are all factual statements correct and adequately supported by citations?

Yes

Are arguments sufficiently supported by evidence from the published literature?

Yes

Are the conclusions drawn balanced and justified on the basis of the presented arguments?

Yes

Is the argument information presented in such a way that it can be understood by a non-academic audience?

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Does the piece present solutions to actual real world challenges?

Yes

Is real-world evidence provided to support any conclusions made?

Yes

Could any solutions being offered be effectively implemented in practice?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Educational Technology, Online learning, Digital Badges, Sustainability Education, Drama Education.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 03 July 2023

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May Portuguez Castro 

Pontificia Universidad Católica de Perú, Lima, Peru

The authors conduct a review of the concept of CBL (Challenge-Based Learning) and its application in a potential course related to sustainability. They also perform a literature review of studies related to the topic and identify, using the TPACK (Technological Pedagogical Content Knowledge) model, the technopedagogical elements of the methodology. They also identify the need for further studies related to online courses, so they aim to address the concept in a way that can be expanded in these environments.

I have reviewed this document, I can provide the following comments and recommendations:

The paper provides a comprehensive review of the concept of CBL and its application in the context of sustainability. The authors have done a good job summarizing the relevant literature and presenting a clear understanding of the topic.

I recommend seeking more recent literature, especially with cases that have been conducted during and post-pandemic, to identify through empirical studies what challenges were encountered in implementing this methodology.

In addition, it is important to identify new lines of research that may have emerged in this context. This can help to explore any innovative approaches or adaptations of CBL methodology that have been developed to address the unique challenges and opportunities presented during and after the pandemic.

It is commendable that the authors have also considered the potential application of CBL in online courses. Given the increasing popularity of online education, exploring how CBL can be adapted and implemented effectively in online environments is crucial.

The identification of techno-pedagogical elements using the TPACK model is a valuable contribution to the research. It helps to understand the integration of technology, pedagogy, and content knowledge within the CBL methodology.

One suggestion for future research is to conduct empirical studies that evaluate the effectiveness of CBL in different educational settings. This could involve assessing the learning outcomes, student engagement, and overall satisfaction with the CBL approach.

Additionally, it would be beneficial to investigate any challenges or barriers that instructors and students may encounter when implementing CBL, particularly in online courses. Understanding these challenges can inform the development of strategies and support systems to overcome them.

The paper could also benefit from providing practical examples or case studies of successful implementations of CBL in sustainability-related courses. This would help readers visualize how CBL can be applied in real-world educational contexts.

Overall, the paper is interesting and can support teachers who need to use this methodology. Considering that these suggestions can be improved upon, I would recommend presenting a more updated literature review. This would provide a comprehensive understanding of the latest research and developments in the field, ensuring that the paper remains relevant and valuable to its readers.

Is the topic of the opinion article discussed accurately in the context of the current literature?

Partly

Are all factual statements correct and adequately supported by citations?

Partly

Are arguments sufficiently supported by evidence from the published literature?

Partly

Are the conclusions drawn balanced and justified on the basis of the presented arguments?

Yes

Is the argument information presented in such a way that it can be understood by a non-academic audience?

Yes

Does the piece present solutions to actual real world challenges?

Yes

Is real-world evidence provided to support any conclusions made?

Yes

Could any solutions being offered be effectively implemented in practice?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Educational innovation

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Comments on this article

Version 1

Reader Comment 28 Jun 2023

David Ernesto Salinas-Navarro, Aston University, Birmingham, United Kingdom

This work brings a relevant and update topic to provide active learning for online students, which represents by itself a challenge and an enormous need to for learning engagement. The paper is properly structured and written. However, a deeper exploration of the CBL literature is required as a number of claims and limitations of this approach are mentioned, which have been already explored, overcome, and/or clarified in recent work. Therefore, I strongly suggest to look at more recent literature in the field from 2020 onwards. Moreover, the description of and definition of online education is still limited and weakly explored. Finally, there is a weak description of HOW to develop and implement CBL in online education to make this work transferable. Accordingly, a model, framework or module could help for this purpose.

Competing Interests: I have no conflict of interest commenting on this article.

Reader Comment 08 Aug 2022

Dr. Amaresh Jha, GD Goenka University, Gurugram, India

Challenge based learning and its implications on online and physical mode of learning is an interesting area of inquiry. Though the study claims that online CBL motivates learners the "transactional distance" under the purview of this study needs some empirical grounding to make such conclusions. But since this is an opinion article the review seems well structured.

Competing Interests: There is no competing interest.