# Exploring the implementation of challenge-based learning for sustainability education in Dutch secondary education

Environmental Education Research

Routledge
Taylor & Francis Group

ISSN: 1350-4622 (Print) 1469-5871 (Online) Journal homepage: www.tandfonline.com/journals/ceer20

# Exploring the implementation of challenge-based learning for sustainability education in Dutch secondary education: teachers' experiences

Bart G. Schutte, Dury Bayram, Johanna Vennix & Jan van der Veen

**To cite this article:** Bart G. Schutte, Dury Bayram, Johanna Vennix & Jan van der Veen (2025) Exploring the implementation of challenge-based learning for sustainability education in Dutch secondary education: teachers' experiences, Environmental Education Research, 31:6, 1166-1192, DOI: 10.1080/13504622.2025.2458723

**To link to this article:** https://doi.org/10.1080/13504622.2025.2458723



Published online: 02 Feb 2025.

ENVIRONMENTAL EDUCATION RESEARCH
2025, VOL. 31, NO. 6, 1166–1192
https://doi.org/10.1080/13504622.2025.2458723

Routledge
Taylor & Francis Group



# Exploring the implementation of challenge-based learning for sustainability education in Dutch secondary education: teachers' experiences

Bart G. Schutte, Dury Bayram, Johanna Vennix and Jan van der Veen

Eindhoven School of Education, Department of Applied Physics and Science Education, Eindhoven University of Technology, Eindhoven, The Netherlands

**ABSTRACT**

Challenge-based learning (CBL) offers a promising approach for integrating education for sustainable development (ESD) in secondary schools. However, despite the growing body of knowledge on the implementation of CBL in higher education, less is known about its implementation in secondary education. This qualitative study investigated how secondary education teachers implement CBL using an adapted CBL compass, collecting data through semi-structured interviews with teachers ($n=8$) and observations of teachers interacting in professional learning communities ($n=26$). Results indicated that CBL in secondary schools involves meaningful, real-life challenges aligned with students' interests, fostering citizenship skills and disciplinary knowledge through a student-centered approach, with teachers acting as coaches. Despite enthusiasm for CBL for ESD, teachers faced obstacles such as overloaded curricula, inflexible learning outcomes, and logistic issues in interdisciplinary collaboration. These findings can guide educators in overcoming these obstacles and encourage curriculum integration of ESD using CBL.

**ARTICLE HISTORY**
Received 26 June 2024
Accepted 20 January 2025

**KEYWORDS**
Challenge-based learning; education for sustainable development; secondary education

## Introduction

Education that empowers students to address emergent global challenges and guides them in understanding how to contribute to resolving these issues should have a permanent place in the curriculum. Unfortunately, students in secondary education (SE) currently have limited exposure to this in their educational programs. It is crucial for students to comprehend the complexities of scientific issues and recognize their role in promoting a sustainable future, leading to more informed and responsible citizens (Bayram-Jacobs et al. 2022).

Education for Sustainable Development (ESD) aims to equip students with the knowledge and skills to tackle environmental, economic, and social challenges (UNESCO, 2020). Sustainable development involves meeting present needs without compromising the ability of future generations to meet theirs, striking a balance between economic, social, and environmental concerns. To prepare students for this task, competencies such as communication, critical and creative

**CONTACT** Bart Schutte b.g.schutte@tue.nl https://www.linkedin.com/in/bart-g-schutte/ Eindhoven School of Education, Department of Applied Physics and Science Education, Eindhoven University of Technology, Groene Loper 3, Eindhoven, 5600 MB, The Netherlands

thinking, collaboration, reflection, innovation, and holistic understanding are essential (Takala & Korhonen-Yrjänheikki, 2019).

One approach to developing these competencies and preparing students to become informed citizens is through challenge-based learning (CBL), a pedagogy that is growing in popularity for addressing today's pressing challenges by actively engaging students in solving real-world problems (Castro & Gómez Zermeño, 2020). At the core of CBL is a call to action, encouraging students to initiate change by conducting research, brainstorming viable strategies, and presenting and implementing solutions to address the challenge (Johnson & Adams, 2011). Compared to traditional education, studies show that CBL leads to significant improvements in innovative thinking skills (Martin et al. 2007) and higher academic performance (Membrillo-Hernández et al. 2019).

Furthermore, extensive research has shown the benefits of this approach for ESD in higher education (e.g. Castro & Gómez Zermeño, 2020; Malmqvist et al. 2015; Martínez-Acosta et al. 2022), even in comparison to similar learner-centered pedagogies (Menchaca-Torre et al. 2024; Sukackė et al. 2022), given that this approach immerses students in authentic, complex challenges, reflecting the complex nature of sustainability issues. For example, CBL has been shown to increase students' awareness of local environmental issues and their ability to formulate ways to address both local and global challenges (Martínez-Acosta et al. 2022), as well as improve their problem formulation skills and deepen their understanding of sustainable development principles (Rådberg et al. 2020). By integrating sustainability issues into the educational curriculum, CBL prepares students to actively contribute to sustainable solutions, aligning with the overarching goal of ESD.

However, despite the extensive literature on CBL, the wide variety of implementations and conceptualizations presents difficulties for practitioners in designing their educational strategies. Publications on CBL span standardized frameworks, hybrid approaches, and more generalized models where only the challenge is incorporated (Gallagher & Savage, 2023). Furthermore, recent years have seen a more critical approach emerge regarding the existing state of CBL literature (van den Beemt et al. 2023). This critique stems from the fact that many studies treat CBL as a model teaching method or pedagogical intervention rather than a comprehensive educational approach, which encourages a deeper, holistic understanding of production of knowledge and learning processes (Gallagher & Savage, 2023; Leijon et al. 2022; van den Beemt et al. 2023). As a result, several attempts have been made to reconceptualize CBL as an educational approach (Gallagher & Savage, 2023).

In addition, the literature on CBL is mostly grounded in the higher education context, leaving uncertainty as to whether the same dimensions of CBL are involved in SE, how teachers implement them, and what their experiences involve. In a similar vein, although CBL has proven effective for ESD in higher education, it remains uncertain whether this holds true for SE, given the differences in educational contexts that influence ESD approaches. For instance, implementing ESD in SE requires a systemic and holistic integration, shifting it from the periphery to the core of the school curriculum (Jucker, 2011). This underscores the importance of interdisciplinary, holistic approaches to address the complexity of sustainability challenges (Taylor et al. 2019). However, the same interdisciplinary focus becomes a challenge in SE, where educational structures often hinder such integration (Stables & Scott, 2002). SE curricula are typically organized into rigid disciplinary silos managed by different departments, each confined to distinct 'realms of knowledge' (Nixon et al. 1999). Moreover, secondary school teachers' understanding of ESD may vary depending on their educational backgrounds (Borg et al. 2012), further complicating implementation. Consequently, the logistical and organizational challenges of cross-disciplinary programs in secondary schools are significant (Jones et al. 2012).

Therefore, given the challenges educators face in implementing CBL, the uncertainty surrounding CBL's positioning, and the limited research on the implementation and dimensions of CBL in Dutch SE, this study focuses on the characteristics of CBL in SE within the context of ESD, as well as the views and experiences of secondary school teachers in designing and implementing CBL.

## Theoretical background

Interestingly, while CBL has mostly been studied in the context of higher education, its roots go back to SE, beginning in 2008 with an Apple-sponsored project called 'Apple Classroom of Tomorrow-Today' (Nichols and Cator 2008). These days, CBL is implemented in different educational contexts, ranging from primary schools to universities (Doulougeri et al. 2024; Sukackė et al. 2022). Across these contexts, CBL can be defined as an approach in which students actively engage with relevant, real-world situations to identify, analyze and design solutions to socio-technical problems. This method involves multidisciplinary learning experiences and collaboration with multiple stakeholders to develop environmentally, socially, and economically sustainable solutions (Rådberg et al. 2020; Sukackė et al. 2022). The CBL process typically follows three interconnected phases: (1) the engage phase, where students refine a broad idea or problem into an actionable and concrete challenge; (2) the investigation phase, where students conduct research to build a solid foundation for creating practical and sustainable solutions; and (3) the acting phase, where students develop and implement solutions based on evidence gathered throughout the previous stages (Nichols and Cator 2008; Sukackė et al. 2022).

CBL draws on elements from other student-centered and active learning approaches, including problem-based learning (PBL), project-based learning (PjBL), and design-based learning (DBL). With its focus on hands-on activities, real-world applications, and deep engagement in the learning process, CBL aligns closely with broader educational theories such as experiential learning and active learning. In addition, it emphasizes student motivation and ownership of the learning process, which relates to self-determination theory (Doulougeri et al. 2024). Furthermore, CBL's learner-centered nature reflects the social constructivist paradigm, where knowledge is actively constructed and transformed through student participation rather than passively acquired.

### *CBL in the landscape of student-centered pedagogies*

Positioning CBL alongside other student-centered pedagogies such as PBL, PjBL, and DBL reveals overlapping core principles, including problem orientation, contextual learning, self-directed learning, and collaboration (Sukackė et al. 2022). The operationalization of these approaches often blurs distinctions, with similarities and differences appearing nuanced in practice (Doulougeri et al. 2024; Sukackė et al. 2022). The systematic review by Sukackė et al. (2022) highlighted that most studies do not clearly distinguish between problems, projects, and challenges, often taking these terms for granted. However, unlike PBL and PjBL, CBL emphasizes co-created challenges involving students and stakeholders, where learners refine broad topics into manageable, self-determined challenges, with the teacher acting as a facilitator (Membrillo-Hernández et al. 2019; Menchaca-Torre et al. 2024). PBL and PjBL, on the other hand, are often characterized by predefined problems created by teachers for knowledge acquisition (Doulougeri et al. 2024; Van den Beemt et al. 2023). DBL also differs in that design challenges are typically more specific and focus on the creation of products or artifacts (Doulougeri et al. 2024; Taconis & Bekker, 2023).

In addition, CBL is characterized by its emphasis on societal problems and solution-oriented processes, which distinguishes it from the more product-focused PBL (Gallagher & Savage, 2023; Menchaca-Torre et al. 2024). A comparative study in a sustainable development engineering program found no significant differences in academic performance between PBL and CBL, but students in CBL developed soft skills such as decision-making and collaboration through engagement with external stakeholders and real-world challenges (Menchaca-Torre et al. 2024). Sukackė et al. (2022) also highlighted the suitability of CBL for ESD as it focuses on socially relevant challenges, stakeholder involvement and co-creation processes. Furthermore, In CBL, students have the freedom to choose and define the specific aspects of the challenge they want to solve, fostering deeper engagement and improving success (Sukackė et al. 2022).

From an ESD perspective, it is furthermore valuable to position CBL alongside other approaches and pedagogies that emphasize environmental sustainability, such as place-based education (PBE) and the whole school approach (WSA). This positioning is particularly relevant given their emphasis on SE and their benefits for ESD (e.g. Gericke et al. 2024; Li & Shein, 2023; Mogren et al. 2019; Ver Steeg, 2019). PBE focuses on experiential, community-based learning that strengthens connections to local cultures, environments, and contexts (Gruenewald, 2003; Sobel, 2004) and serves as an umbrella term rather than a specific approach (Yemini et al. 2023). While both PBE and CBL emphasize real-world, student-centered learning, their focus and approaches differ. The place-based aspect of PBE can be embedded in a CBL project when local stakeholders are involved, although this is not always the case. In addition, PBE implementation is more flexible, integrating local experiences into the curriculum and allowing teachers to adapt lessons to specific settings. In contrast, CBL takes a more structured approach in which students collaboratively define and address both local and global societal challenges (Van den Beemt et al. 2023).

Similarly, WSA provides a holistic framework for redesigning education that involves co-creative, systemic efforts by all stakeholders to engage students in complex sustainability challenges (Hargreaves, 2008; Mogren et al. 2019; Mathie & Wals, 2022). While WSA aligns with CBL in its vision, it goes beyond pedagogy to transform education at multiple levels, including curriculum, professional development, school practices, community relationships, leadership, and vision. In its implementation, WSA embeds sustainability throughout the school system, incorporating sustainable practices beyond the classroom, while CBL is more project-driven, focusing on students working on specific real-world challenges. WSA calls for systemic change by engaging leadership, policy, and the broader school community in a unified sustainability effort.

### *ESD and Dutch secondary education*

Dutch secondary schools have considerable autonomy in choosing their teaching methods and curricula, as long as they meet government standards for subjects, performance targets, and exams (de Wolf & de Hamer, 2015; Luijkx & de Heus, 2008). This autonomy includes the option to incorporate sustainable development (SD), often supported by local organizations, at the discretion of the school (Wesselink & Wals, 2011). Informed by three educational governance institutions (de Wolf & De Hamer, 2015) with considerable influence on the Dutch education system, ESD in the Netherlands, can be described as learner-centered, future-oriented, and action-based. It aims to raise students' awareness of societal issues while fostering problem-solving skills involving multiple stakeholders, and integrating environmental topics into existing subjects (Kopnina, 2018; Wesselink & Wals, 2011). Although ESD is not a mandatory part of Dutch curricula, schools can integrate it by aligning themselves with various core objectives that indirectly address SD. However, this often results in fragmented efforts where ESD elements are limited to subject-specific approaches rather than interdisciplinary programs. Nevertheless, the freedom of education allows schools to make ESD a core part of their curricula. If they choose this, schools may receive accreditation as 'eco-schools' or 'energy schools' (Van der Waal, 2011). These initiatives, however, are often led by teachers or school leaders and require personal effort due to factors such as the lack of repositories of projects or dedicated schoolbooks (de Wolf & de Hamer, 2015).

### *The CBL-compass*

This study adopted the CBL Compass for Higher Education (van den Beemt et al. 2023). This conceptual framework builds on commonly identified CBL characteristics (Gallagher & Savage, 2023; Leijon et al. 2022) by incorporating dimensions and indicators that capture the full range of observed CBL implementations. Rooted in current CBL practice, the framework emphasizes the commonalities across CBL applications in education rather than focusing on theoretical discrepancies or variations in descriptions. It accommodates differences in CBL characteristics

across study components and curricula and provides a clear methodological approach that benefits both practitioners and researchers by clarifying the components of CBL implementations (Leijon et al. 2022; van den Beemt et al. 2023).

Several factors make the focus on common characteristics and the flexibility to capture diverse CBL implementations particularly relevant to this study. First, SE faces unique challenges in implementing ESD. Second, the autonomy of schools in designing their own curricula, setting educational priorities, and defining pedagogical approaches leads to significant variability in how CBL is implemented across schools. Third, ESD initiatives are often driven by individual teachers within the broader structures of their schools. Teachers often have to adapt their efforts to fit within these structures while navigating school-based obstacles such as workload, subject focus, and available opportunities for collaboration.

The CBL Compass framework adopts the why-how-what approach, identifying CBL educational processes at the elements of vision, teaching and learning, and support (van den Akker, 2003; van den Beemt et al. 2023). The element of *vision* in the framework includes the goals and motivations of a CBL implementation, addressing the question of why students learn (Doulougeri et al. 2022). This aspect is clarified through challenge characteristics such as their real-life and open-ended nature, the involvement of stakeholders, and the incorporation of global themes (van den Beemt et al. 2023). The element of *teaching and learning* corresponds to the methods used to achieve the goals outlined in the vision, addressing how students learn (Doulougeri et al. 2022). Dimensions associated with this element relate to aspects of course design, including learning objectives, content, teaching and learning activities, and assessment methods (Fink, 2003; van den Beemt et al. 2023). Furthermore, regarding the element of *support*, insofar as CBL prioritizes student-centered learning with an emphasis on students' active learning, additional support is necessary compared to more traditional teacher-centered approaches. This requires teachers to be realistic about the resources available from the school and, in some cases, stakeholders (Doulougeri et al. 2022; van den Beemt et al. 2023). In addition, support structures are needed to assist teachers not only in designing CBL projects, but also in developing the necessary skills to effectively teach and coach in a CBL context.

### *Present study*

Guided by the theoretical framework proposed by van den Beemt et al. (2023) as adapted for SE (see Appendix A), this study seeks to address the following research questions:

1. How do secondary school teachers implement CBL in the context of ESD?
2. What are teachers' views and experiences concerning the implementation of CBL for ESD?

In addressing these questions, we aim to gain insight into the implementation of CBL for ESD and explore how teachers and schools navigate obstacles. Consequently, this research may guide curriculum design for ESD integration through CBL, offering teachers direction in formulating challenges, including stakeholder involvement, and aligning challenges with existing curriculum content.

## Methods and materials

### *Research design*

This study employed an exploratory qualitative research design, involving semi-structured interviews and observations of several group discussions within a professional learning community (PLC). Observations of groups within the PLC setting, focused on the development of CBL education, alongside individual interviews, allowed for a detailed exploration of teachers' experiences and views regarding their design and implementation of CBL.

### Context of the professional learning community

The study was part of a planned four-year partnership, beginning in 2022, between a group of schools and the teacher education program at the researchers' university. This partnership was established to address the limited integration of sustainability education in secondary schools through CBL. Integrating CBL for sustainability education into the curricula of the affiliated schools was linked to the advancement of STEM education, as well as an emphasis on citizenship in science education and the connections between these areas.

To facilitate this integration, a cross-school PLC was formed, initially bringing together eight teachers from different schools in the region. PLCs, characterized by reflective inquiry and collaborative practice, have been shown to promote effective teacher development (Vanblaere & Devos, 2015). Accordingly, teachers in the PLC engaged in a cyclical design process, meeting eight times annually in central sessions and holding additional in-depth discussions in pairs at their respective schools. The goal of these collaborative design activities was to develop, test, and evaluate CBL implementations tailored to various school contexts.

In the first year, the PLC set clear goals and expectations, drawing on external expertise by inviting specialists in CBL and ESD. Teachers collaborated on lesson plans, shared feedback on CBL designs, and reflected on their implementation obstacles. This collaborative, reflective approach aligns with key aspects of effective PLCs, such as reflective dialogue, where teachers deeply explore issues related to curriculum, instruction, and student learning (Stoll et al. 2006). Furthermore, sharing practice, especially the co-design of teaching strategies, represents a higher form of professional collaboration, strengthening the PLC's impact on teaching practices (Vanblaere & Devos, 2015).

The knowledge and skills gained during this first phase laid the groundwork for subsequent years of the project and PLC meetings. For instance, pilot versions of CBL projects developed during this initial year informed subsequent PLC activities in the 2023–2024 academic year. During this second phase, the number of participating teachers increased from eight to 26, enabling a broader round of CBL development and refinement. The expanding network of teachers played a crucial role in ensuring that the curriculum innovations introduced through CBL were sustained and reinforced in the following years.

### Participants

The study involved 26 secondary school teachers from seven different schools who actively participated in the PLC during the second year. Eight teachers from the PLC were selected for interviews based on their participation in the first year of the project, indicating more experience and expertise in the design and implementation of CBL projects (see Table 1). Thus, a purposeful sampling strategy was employed (Creswell, 2003). These teachers assumed the role of facilitator, supporting other teachers in their design and implementation of CBL education. All participants in this study provided informed consent.

### Data sources and data collection process

Data were collected from five monthly 3-h PLC meetings and eight semi-structured interviews, each lasting approximately 1 h. The data included field notes from participatory observations during the PLC meetings and transcripts of the interviews. In preparation for data collection, a guiding tool was developed based on the CBL compass by van den Beemt et al. (2023; see Appendix A). This tool was adapted for the SE context and provided structure for the interview protocol and observations during the PLC meetings. The dimensions and indicators from the CBL compass were used as initial reference points in the development of the guiding tool,

**Table 1.** Demographics for interview participants.

| Participant (school) | Teaching subject(s) and CBL project | Teaching experience (years) |
|---|---|---|
| Robert (1) | Biology and Big History – EcoKino | 3 |
| Frank (2) | Philosophy – Sierra Leone | 15 |
| Jessica (1) | English – AMStory | 6 |
| Daisy (3) | English – Green badge | 9 |
| Matthew (3) | Science and Technology – Sustainable campus | 6 |
| Steven (4) | Physics and Science – ASM | 15 |
| Benjamin (5) | Physics – Sustainable energy | 10 |
| Brian (6) | Biology – Disability tool | 6 |

*Note.* Names are pseudonyms.

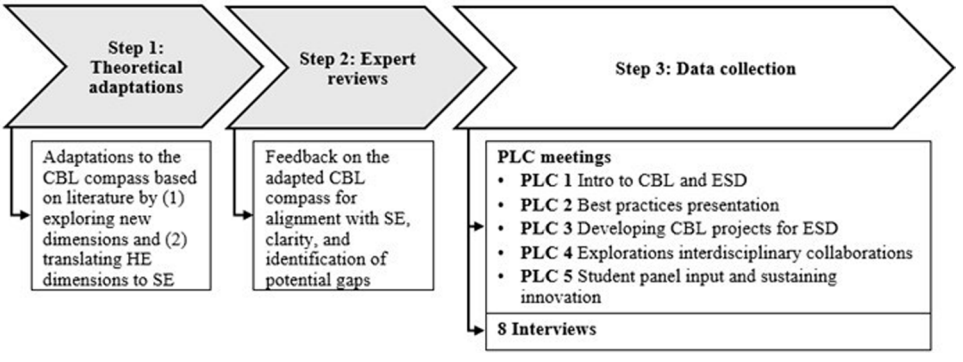


**Figure 1.** Overview steps development guiding tool.

involving several steps to align this model with the context of SE: (1) theoretical adaptations informed by relevant literature on CBL in SE, and (2) expert reviews (see Figure 1 for an overview of the research steps).

First, adaptations to the CBL compass were made, based on the limited literature on CBL in SE. Dimensions and indicators were modified through rephrasing, rearranging, adding, or removing them. For example, the T-shaped professional dimension common in engineering education and present in the original CBL compass (van den Beemt et al. 2023), assumes that team members each have their own expertise, a condition not applicable to SE, where students share the same knowledge. This dimension was replaced by the citizenship dimension, highly relevant in SE in the Netherlands, which addresses skills such as critical and creative thinking (Fala et al. 2012; Johnson & Adams, 2011).

Secondly, for quality assurance and to address any structural issues beforehand, the tool underwent evaluation by five independent experts in one-on-one sessions (Olson, 2010). These experts included assistant professors with expertise in CBL in higher education and project-based STEM in SE, as well as educational scientists specializing in technology-oriented education programs, which share commonalities with CBL. Their diverse specializations ensured feedback from various perspectives (Olson, 2010). Significant changes resulting from this feedback included adding the term 'student-centered' to underscore its centrality in CBL, and emphasizing that learning is triggered by real-life challenges, fostering uncertainty, and encouraging student ownership.

The tool was initially created in English, but was translated into Dutch for the interviews, as most participants felt more at ease expressing their views and experiences in their native language. To ensure translation accuracy, a backtranslation (McGorry, 2000) to English was conducted and then compared to the original tool.

During the PLC meetings, involving all teachers, the first author, taking a participatory observational role, compiled the field notes. More specifically, the author participated in discussions of the design of materials and implementation of projects, helped to clarify educational concepts when needed, and asked critical questions informed by the guiding tool as a way to structure the observations. The observations were primarily conducted to grasp common themes teachers grappled with in the meetings in developing CBL education.

Semi-structured interviews were conducted to gather detailed data on teachers' CBL implementations and experiences, which took place during the past school year. See Table 2 for the CBL implementations in which they had been involved (see Appendix B for a more detailed description of the CBL projects, including how CBL was integrated, the sustainability issues/themes addressed, and the developed products and solutions). The interviews took place between PLC meetings 3 and 4. The interviews were divided into two phases. The first phase focused on teachers' motivations, successes, and difficulties with CBL. The interview protocol for this phase was developed through several steps. First, questions were formulated based on the literature, followed by discussions with the research team to further refine the protocol. Next, a pilot interview was conducted to test the design in practice, which was followed by a final round of revisions. In the second phase, prompted by the interviewer, teachers discussed the guiding tool for CBL in SE, reflecting on specific CBL projects they had taught, considering relevant dimensions and indicators, explaining project choices, and identifying any underemphasized dimensions or indicators. All interviews were recorded and transcribed for analysis. Quotes used from the interviews have been translated into English.

### *Data analysis*

ATLAS.ti qualitative analysis software was used to conduct the data analyses, following the qualitative data analysis spiral proposed by Boeije (2009). The analysis process used both deductive and inductive approaches. Using the deductive approach, 14 categories were derived from the guiding tool (e.g. *real-life open-ended challenges, collaborative learning,* and *teacher support*). The indicators from the guiding tool served as the initial codes, such as, 'authentic', 'challenge-owner' and 'research skills'. A priori codes were also created to address teachers' experiences of difficulties and opportunities for project development (e.g. project development).

During the coding process, a combined approach of open and axial coding was used (Boeije, 2009), resulting in the emergence of new codes, such as 'meaningful learning' and 'responding to student interests' as well as sub-codes. See Appendix C for the final codebook. Transcripts of the interviews and field notes of the PLC meetings were analyzed. After the coding process, the interconnections between teachers' obstacles and opportunities in relation to the categories of the guiding tool were explored using code-occurrence and code-document analysis, with the aim of identifying themes within and across schools. Due to the qualitative nature of phase two of the interview, where teachers evaluated the relevance of the dimensions and indicators, the original scoring method using a 5-point Likert scale was deemed inappropriate. Instead, indicators identified by teachers as highly relevant and applicable in their projects were marked as present, while those deemed irrelevant, and thus not applied, were marked as not applicable, reflecting a deliberate choice. For indicators marked as partial, teachers expressed uncertainty about their applicability to their projects in their specific contexts.

## Results

In this section, we first present findings on CBL implementations and their relationship with the CBL dimensions outlined in the CBL compass for SE based on the interviews. Given the many indicators, only those that stand out as the most applicable or inapplicable will be

**Table 2.** Overview of the CBL implementations.

| School | Student age | Type of implementation (within or outside subject) | CBL implementation (projects) |
|---|---|---|---|
| 1 | 14–15 | Subject implementation; Biology | (A) EcoKino: Students merge ecology with film/cinema elements, identifying social ecological dilemmas and creating artistic products (documentaries, photo galleries). |
| 2 | 12–13 | Subject implementation; interdisciplinary (during weekly project hours) | (B) Sierra Leone: Students collaborate on an SDG-themed project, connecting with Sierra Leonean students, creating a comparative poster, delivering oral presentation. |
| 1 | 14–15 | Project implementation; Arts education | (C) AMStory: Students focus on SDG-related themes, exploring Amsterdam, conducting interviews, presenting at an innovation fair. |
| 3 | 11–14 | Subject implementation; English language and learning | (D) Green badge: Students collaborate on achieving green certification, focusing on SDG-themed topics, e.g. waste management and green spaces. Students present videos for the schoolboard. |
| 3 | 12–15 | Subject implementation; Physics | (E) Sustainable campus: Students collaborate on a year-long CBL project focusing on campus sustainability, selecting from SDG-related themes, and presenting their findings at a scientific fair. |
| 4 | 14–17 | Subject implementation; Physics | (F) Advanced Science and Mathematics (ASM): Students write research proposals on geophysics and SDGs, presenting their findings for summative evaluation. |
| 5 | 13–14 | Subject implementation; Physics | (G) Sustainable energy: Students explore sustainable energy solutions using the Scrum method (describes roles, tools, and meetings to reach a common goal), delivering presentations and posters for assessment. |
| 6 | 11–12 | Project implementation; interdisciplinary (during a project week) | (H) Disability tool: Students collaboratively create tools for those with disabilities, conceptualizing, developing, and presenting solutions for a local external organization. |

discussed. Additional qualitative information from the interviews, relevant to the scoring of the indicators, will also be included in this section. Next, based on outcomes of the interview and PLC meetings, we present the results on the overall compatibility of CBL for ESD in secondary schools. Finally, we present teachers' views and experiences on the elements of 'vision', 'teaching and learning,' and 'support.'

## *Approaches to implementing CBL*

CBL implementations involved real-life challenges promoting self-directed learning, with learning activities aimed to develop citizenship skills, and for subject implementations (see Table 2), acquiring disciplinary content knowledge. Teachers acted as coaches, guiding both the content and relational aspects of learning. However, facilities and support structures for teachers were limited. See Table 3 for a more detailed overview of the results for each dimension per implementation.

7 out of 8 CBL projects presented real-life challenges. Based on further discussion, the projects spanned interdisciplinary ($f = 4$), multidisciplinary ($f = 2$), and monodisciplinary ($f = 2$) approaches, with projects either being implemented in subjects or as stand-alone projects. Only one challenge came from an external challenge owner; others were school-generated ($f = 2$) or had no specific owner ($f = 5$). Without external stakeholders, challenges focused on raising sustainability awareness. CBL fostered student-centered learning ($f = 5$) with deadlines and final product requirements, helping students track progress and explore interests. Some challenges aligned with curricula ($f = 5$), focusing on content knowledge within subject lessons, while others were not integrated into any specific subject ($f = 3$).

All implementations supported the development of citizenship skills. For instance, projects required students to write reflection reports after each lesson or at the end of the project, focusing on communication, collaboration, conflict resolution, and documenting decisions made during problem-solving. Other activities included class discussions and debates. One learning activity featured a classroom debate, with a student serving as moderator, who introduced a sustainability issue while four other students presented different perspectives on the topic. Based on the input gathered, the moderator proposed a solution that considered the needs of all perspectives and incorporated new insights from the class to foster creative thinking. In addition, critical thinking exercises, such as claim testers, allowed students to categorize claims based on intuition, authority, evidence, or logic, helping them assess what to believe and evaluate others' claims. Some projects, specifically the stand-alone projects ($f=4$), explicitly reflected on and assessed citizenship skills. In contrast, the subject-specific implementations ($f=4$) did not include them explicitly in the learning goals, expecting them to develop naturally through the student-centered, collaborative process. Similarly, research skills were part of the learning process, but often lacked specific goals or assessments. Peer learning also occurred implicitly among teammates due to the collaborative nature of CBL. In certain implementations ($f=4$), peer learning was more pronounced, as learning activities encouraged each group member to undertake specialized tasks, fostering interdependence and indirectly promoting peer learning. For example, in one project, all group documents were shared among peers, requiring students to provide feedback specifically on another group's project that focused on a different theme. Other activities to promote peer learning included presentations throughout the project, which allowed students to share knowledge due to the varying content between groups, as well as quizzes given as exit tickets at the end of each lesson to encourage exchange and discussion among the groups. End products were usually summatively assessed, including group presentations at scientific fairs. Final products varied, including videos, photo galleries, posters, models, presentations, and research proposals.

Facilities included materials for final products and experiments ($f=5$), and spaces such as science labs and gymnasiums for fairs ($f=4$). Time and support structures were limited, with some schools ($f=5$) offering minimal help with course design and pedagogy. Some schools ($f=4$) provided limited teacher development opportunities in coaching and CBL skills through workshops or a PLC within their own school.

### *Teachers' views and experiences of CBL for ESD in secondary education*

In general, teachers indicated that CBL is a valuable approach for ESD, aligning well with its complexity, open-ended structure, and incorporation of real-world issues. For example, when discussing CBL in the context of ESD, one teacher stated:

> Every sustainability theme addresses the students' future and the uncertainties it holds. In this context, the primary skill you want them to acquire is resilience, creativity, or the ability to adapt to changes. Your goal is to shape students who can navigate the evolving world. (Brian)

Furthermore, teachers found that engaging with students' interests and environment and incorporating sustainability issues in this way sparks enthusiasm and curiosity among students, as indicated by another teacher:

> A couple of students were working on soy, starting with the notion that people shouldn't consume it due to deforestation in the rainforest. However, they discovered that 90% of the soy grown in areas once covered by tropical rainforests is used as feed for cattle, contributing to the meat industry… This new understanding significantly shifted their perspective… So, then you see that this kind of project can indeed have an impact on young people. (Robert)

**Table 3.** Scoring of projects based on the CBL compass for SE.

| | Present | Partial | Not applicable |
|---|---|---|---|
| Vision | | | |
| *Real-life open-ended challenges* | | | |
| Real-life | A, B, C, D, E, F, H | G | |
| Authentic | A, C, H | B, D, E, F | G |
| Open-ended | A, C, E, H | B, D, F | G |
| Complex | A, B, D | C, H | E, F, G |
| Interdisciplinary | B, C, D, H | E, F | A, G |
| *Global themes* | | | |
| Transformative and integrative value | H | A, B, E | C, D, F, G |
| Contribution | H | E, D | A, B, C, F, G |
| *Student centered* | | | |
| Self-directed learning | A, B, D, F, G | C, E, H | |
| Ownership | A, B, D, E | F, H | C, G |
| Student interests | A, B, C, D, H | | |
| Meaningful learning | A, B, C, H | | |
| *Involvement of challenge owner* | | | |
| Challenge owner | H | D, E | A, B, C, F, G |
| External stakeholder | A, B | C, E | D, F, G, H |
| *Curriculum* | | | |
| Curriculum alignment | A, E, F, G | C | B, D, H |
| **Teaching and learning** | | | |
| *Citizenship* | | | |
| Citizenship skills | B, C, D, E | A, F, G, H | |
| *Inquiry-based learning* | | | |
| Content knowledge acquisition | A, E, F, G | D | B, C, H |
| Define own objectives | | D, E | A, B, C, F, G, H |
| Inclusion of different perspectives | | A | B, D, E, G, H |
| Critical reflection | A, B, C, D, E, F, G | | H |
| Research skills | A, B, C, D, E, F, H | | G |
| Meta-cognitive skills | B, C, E, F | G | A, D |
| Dealing with uncertainty | A, B, E | | C, F, G, H |
| *Collaborative learning* | | | |
| Divergent and convergent reasoning | E, F | C | |
| Interdependence of team members | A, B, F, G | C, E | |
| Peer learning | G | A, B, D | |
| *Assessment* | | | |
| Process | A, B, C, E, G, H | | D, F |
| Products | A, B, C, E, G, H | | D, F |
| Individual | B, G | C, E | A, D, F, G, H |
| Team contributions | A, B, C, E, G, H | | D, F |
| Formative | B, C, E | A, D | F, G |
| Summative | A, B, E, G | | C, D, F |
| *Teaching* | | | |
| Coaching supports learning | A, B, C, D, E, F, G, H | | |
| Autonomy and structure | B, C, D, E | A, F, H | G |
| Teacher role: coach | A, B, C, D, E, F, G, H | | |
| Support in content space | A, B, D, E, F, G | C | |
| Support in relational space | B, C, D, E | A, G | |
| Collaborate across subjects | | A, E, F | B, C, D, G, H |
| *Learning technology* | | | |
| Tools for learning | E | A | B, D, G, H |
| **Support** | | | |
| *Facilities* | | | |
| Materials | A, B, D, E, G | C | |
| Spaces | A, D, E, G | F, H | |
| Teacher time | A, D | B, F, G, H | C, E |
| Tools | A, D | E | G |
| *Teacher support* | | | |
| Course design and pedagogical support | D, H | A, B, C, E, G | |
| (Coaching) skills CBL context | H | B, C, D, E | G |
| Collegial support | A, D, E | B, F, H | C, G |

*Note.* Some CBL implementations lacked data responses on some indicators. Absent indicates that it was specifically mentioned. If in case the project is not mentioned, it was not clearly discussed.

Project labels: A = EcoKino; B = Sierra Leone; C = AMStory; D = Green badge; E = Sustainable campus; F = ASM; G = Sustainable energy; H = Disability tool.

This quotation further underscores the strength of students' self-regulated learning as a mechanism driving changes in behavior and attitudes through the independent exploration of sustainability issues. This aspect, recognized as a key component of CBL, further reinforces the alignment between learning outcomes related to sustainability education and CBL.

### *Teachers' views and experiences regarding complex and open-ended challenges*

Despite the variety of CBL implementations, covering diverse topics and duration, teachers presented real-life challenges with varying levels of complexity. One teacher stated:

> All CBL activities I engage in are related to sustainability themes. So, each CBL project includes real-life challenges. With my project, they come up with their own projects, and all of them are highly real-life. They all revolve around either their immediate environment or the general surroundings in which they find themselves. (Brian)

The majority of the teachers viewed the complex, open-ended nature of challenges as inherent in real-life situations, integral to education, and essential for students' exploration of diverse perspectives and multiple solution paths. Reflecting this perspective, Robert stated: 'Research is open-ended, and that is crucial. Openness is also closely tied to complexity, as it allows for different perspectives, acknowledging that it is not black and white. Rather, the solution lies somewhere in the middle.' Conversely, other teachers in the PLC faced difficulty in incorporating these aspects in their projects, expressing reservations about the open-ended nature of challenges and suggesting that these may be too demanding for secondary school students to effectively engage with and gain meaningful learning experiences.

Interestingly, teachers prioritized meaningful learning, with the challenge either locally contextualized or closely related to students' real-world experiences. More specifically, Frank and Matthew drew a dichotomy between connecting with students' experiences and interests and the involvement of an external challenge owner. While acknowledging the value of an external challenge owner for enhancing authenticity, they also stressed the importance of challenges that resonate with students' contexts, even without external ownership. Teachers pointed out that having a challenge owner could impose limitations on students' freedom and require substantial time and effort to manage. Therefore, teachers expressed a preference for allowing students' interests to guide their learning process. As Frank stated:

> Teaching students that they learn meaningful and that they can truly contribute to the needs of the stakeholder who has set the challenge is quite challenging because sometimes I don't necessarily have that. Sometimes, I just want them to work from their curiosity.

Nevertheless, teachers who supported having students explore their interests did not necessarily reject the idea of external collaboration. For instance, in the ecoKino project, students were assigned the task of interviewing knowledgeable experts to gain insights into their chosen topic. Alternatively, in the AMStory project, external parties were invited for assessment purposes. To navigate the earlier stated dichotomy, Matthew, for example, invited an external party to explain the problem or challenge and spark enthusiasm, rather than solely serving as a challenge owner:

> It's not necessarily about doing it specifically for someone, but the moment you bring in an external perspective, someone who explains the challenges they face and how they handle them, that makes it genuine. I believe that is the essence, authenticity. Children are keenly aware of whether they are doing something just for the sake of it or if it's a genuine activity.

Overall, although teachers' perspectives diverged regarding the level of open-endedness and complexity in challenges for SE, they were in agreement about the importance of fostering meaningful learning, emphasizing a balance between student exploration and external stakeholder involvement. The latter was acknowledged more for providing authenticity and purpose, rather than for filling the role of a challenge owner.

### *Teachers' views and experiences regarding curriculum alignment*

Aligning with curriculum objectives has proven to be a significant concern and constraint for teachers in designing CBL projects. While some teachers had the opportunity to shape their CBL projects during a project week or had the flexibility to design their curriculum, particularly with the introduction of interdisciplinary subjects such as Big History, nature, life, and technology (NLT), Technasium, and global issues, not all teachers had this flexibility. The rigid curriculum for their discipline limited opportunities for both project-like education and ESD. One teacher stated:

> I don't have the flexibility in my program to let them be so independent. I simply have chapters, and sometimes I can do something extra, but I can't offer them a project like 'sustain the school'. I just don't have the space for that. (Benjamin)

Another teacher, who primarily teaches in upper-SE, had to comply with program assessment and graduation standards when designing ESD projects, as he noted:

> Since the students will soon have to take their exams, I simply have to adhere to the PTA (program of assessment and graduation), which is sent to the inspectorate, and I cannot deviate from that. So, I experienced a disconnect between what I was required to do and where I could take liberties with CBL. I also only had the class for one hour a week, which made it very complex. (Steven)

Moreover, curriculum flexibility also determined how much autonomy teachers could grant students for self-directed learning with open-ended challenges while still fulfilling specific knowledge objectives, a task complicated by CBL's open-ended nature. For instance, Matthew stated, 'If the primary focus is on acquiring knowledge, CBL may not be the most suitable approach. While it can be done, direct instruction, assignments, and reports may be more effective.' This reflects the uncertainty teachers faced in shaping standardized summative assessments for a curriculum that expects uniform learning outcomes for all students, while students work in an open-ended and self-directed learning environment where learning outcomes are anything but uniform. Teachers tried different strategies such as using exit cards or quizzes during projects to ensure that mastery of knowledge matched curriculum goals. However, finding the right balance between openness and structure remained difficult.

### *Teachers' views and experiences regarding interdisciplinarity*

Besides curriculum constraints, teachers highly valued interdisciplinarity for addressing the complex nature of sustainability issues, but faced limitations due to organizational and logistic aspects of SE. For example, time constraints and the siloed nature of subject curricula made it difficult for teachers to schedule meetings with colleagues and explore cross-curricular collaborations. One teacher stated:

> There just isn't always time in our classroom to collaborate with other subject teachers. I would love it if my geography or English colleagues could come and see how they could contribute to my project, but in practice that contact always happens outside of class. Everyone has their own lessons and preparation, so I see very few opportunities to work with other teachers. (Frank)

Even in cases where collaboration existed, implementation remained challenging due to scheduling conflicts and subject matter alignment issues, as another teacher explained:

> We have an interdisciplinary teaching team in which CBL is designed, involving subjects like biology, arts and crafts, and myself as a physics teacher. Despite this collaboration, I was the only one teaching it because it was very difficult to organize how we could merge the different curricula and how to connect the lessons. (Steven)

Interestingly, in another instance where an interdisciplinary project was already developed, it lacked support from the school board. As one teacher noted:

> The school leadership agreed that the project aligned with the science curriculum, but it required too many hours for one teacher. They were hesitant to involve other teachers because of the challenge of teaching not only physics, but also biology and chemistry. Even with a plan to divide the content among subject teachers, they still did not approve. (Matthew)

Due to these obstacles, several teachers confined to their own disciplines but still valuing the interdisciplinary nature of ESD and CBL took different approaches to achieve some level of interdisciplinarity. For instance, one physics teacher explored possibilities for interdisciplinarity within his own subject, leading to the topic of extreme weather conditions, which integrated perspectives from geography into physics. Frank and Robert instead sought to collaborate with colleagues from other subjects, aiming at expanding their projects with a multidisciplinary perspective. However, scheduling constraints hindered interdisciplinary discussions.

### *Teachers' views and experiences regarding teaching and learning*

In all implementations, both subject-related and non-related projects focused on facilitating students' development of citizenship skills such as critical and creative thinking, assessing reliable sources, and communicating with peers. As one teacher stated:

> I fully support citizenship skills. It holds immense significance in the present era… This was evident in 2006 when approximately 40% of graduates entered professions that did not exist when they began secondary school. In the past, individuals were trained for specific roles, with distinct skills and knowledge. However, today, the emphasis is on teaching people how to learn and conduct research. (Matthew)

This quote further underscores the value of citizenship skills, portraying their relevance beyond graduation and promoting the importance of lifelong learning.

### *Teachers' views and experiences regarding the teacher's role*

Teachers transitioned from traditional instruction to coaching roles, adapting to the open-ended nature of the challenge and a student-centered approach. In this coaching role, teachers primarily offered feedback on the process rather than focusing on content, recognizing that students often delved into topics beyond their expertise, as one teacher stated:

> You won't have expertise in every subject students delve into. It's something you need to acknowledge and overcome. As a result, you're less of a traditional teacher and more of a coach. This means working alongside students, and if they pose a question you can't answer, responding with, 'I don't know that either. Let's figure it out together, or I'll look it up for you.' (Frank)

However, this coaching role presented difficulties, particularly in scaffolding learning while encouraging student responsibility. The complexity of sustainability issues further complicated this dynamic process, leading teachers to adopt various approaches, such as providing pedagogically simplified issues or multiple theme options, while others allowed complete flexibility. For instance, Robert, embracing the latter, guided students through the stages of research question development, particularly when they struggled with the concept of complete flexibility, and used a questionnaire to help them narrow down their questions.

### *Teachers' views and experiences regarding support*

Teachers across all schools perceived varying levels of support from school leadership in developing and implementing CBL for ESD. While the initiative to engage in PLC discussions on these topics was school-led, not all teachers experienced robust support aligned with the school's vision and strategy. Some teachers found the support superficial, expressing concerns about the compatibility of the school's vision with the open-ended nature of teaching CBL for ESD, as one teacher stated:

> Does the school and its leadership recognize the learning opportunities inherent in exploring unconventional paths driven by students' passions, enthusiasm, and curiosity? This aspect transcends mere facilities, it should be in the school's vision. Both the school and the teachers must acknowledge that going beyond conventional boundaries can yield significant educational benefits. Without this clarity in the school's vision, our innovational efforts can be constrained. (Frank)

Insufficient time allocated for project development posed additional difficulties for some teachers. Moreover, there was a perceived need for interdisciplinary meetings involving school leadership and colleagues in order to sustain CBL projects in the curriculum. In addition, as these CBL implementations were pioneering efforts, support structures to assist teachers in developing necessary skills, such as the coaching skills required in a CBL context, had not yet been established. Two schools had customer relation officers to recruit organizations as potential challenge owners, relieving teachers of this task. However, despite the availability of this opportunity, teachers did not capitalize on it when shaping their CBL projects.

## Discussion

This study investigated the dimensions of CBL as implemented in SE for ESD and examined the views and experiences of the secondary school teachers involved. While other studies have explored implementations, conceptualizations, and characteristics of CBL in higher education (e.g. Doulougeri et al. 2024; Gallagher & Savage, 2023; van den Beemt et al. 2023), this study focused on capturing the variety of CBL implementations in secondary education within the context of ESD. Although the CBL implementations in this study varied widely, the findings of the study revealed that the majority involve real-life, meaningful challenges promoting self-directed learning, with activities aimed at developing citizenship and disciplinary knowledge acquisition. Teachers assumed the role of coaches, guiding student groups that worked collaboratively and engaged in inquiry-based learning regarding both content and relational aspects. Teaching support regarding course design, implementation structures, and professional development was limited or still in the early stages of development within the teachers' respective schools.

In addition, this study captured secondary school teachers' views and experiences regarding CBL in the context of ESD. Although teachers expressed enthusiasm for CBL, they encountered obstacles in developing sustainability education. These included limited opportunities for open-ended and fully student-centered approaches due to an overloaded curriculum, inflexibly learning outcomes, and logistic difficulties in interdisciplinary collaborations with colleagues. They acknowledged the value of external collaborations for authenticity, but emphasized the importance of contextually relevant challenges, often opting for limited collaborations such as interviews and assessments, instead of having a challenge owner.

### *Approaches to implementing CBL*

Consistent with the framework proposed by van den Beemt et al. (2023) and other CBL conceptualizations, challenges were primarily real-life. CBL projects were implemented either within subjects, aiming to develop citizenship skills and facilitate knowledge acquisition, or as stand-alone projects, focusing primarily on citizenship. Emphasizing the cultivation of citizenship skills fosters awareness of sustainable development, particularly within the local context, thereby nurturing informed and responsible citizens (Bayram-Jacobs et al. 2022). Half of the CBL implementations involved a form of external collaboration, such as assigning students to interview a knowledgeable other outside of school, thereby enhancing authenticity even in the absence of an external challenge owner. Research has shown that when secondary school students engage with stakeholders beyond the classroom, they exhibit greater motivation and perceive

their work as more relevant and meaningful (Shuptrine, 2013). Students worked collaboratively, adopting an inquiry-based approach to develop ways to address these challenges, with teachers primarily assuming the role of a coach in scaffolding students' learning process. Interestingly, the difficulties in SE reported in this study focused more on connecting with students' life experiences, providing them with the chance to pursue their own interests through meaningful learning. This finding is in line with the study of Johnson et al. (2009), suggesting that challenges should hold meaningful relevance to students' lives and have an impact on their immediate environment, such as schools or local communities, in addition to being connected with the real world. By doing so, this approach enhances students' engagement with the challenges and their intrinsic motivation to learn (Iwatani et al. 2020; Shuptrine, 2013).

### *Teachers' views and experiences*

The results indicate that CBL is an effective approach for ESD, as many teachers emphasized the development of citizenship skills that are vital for addressing sustainability issues (Johnson et al. 2009). Teachers observed increased enthusiasm and curiosity among students when they were able to explore their own interests within the context of sustainability-related challenges, positively influencing their behavior and attitudes toward sustainable development. This finding aligns with other studies concluding that the application of active learning approaches contributes to the acquisition of skills and attitudes that promote sustainable development (Castro & Gómez Zermeño, 2020).

In addition, teachers valued the interdisciplinary, complex, and open-ended nature of sustainability issues, which align well with the holistic and student-centered approach of CBL. Research has shown that allowing students to work on complex, interdisciplinary problems and make meaning of their education provokes their interest in sustainable development (Castro & Gómez Zermeño, 2020; Rådberg et al. 2020). However, teachers worried that the open-ended and complex nature of the challenge could overwhelm secondary school students, hindering their ability to learn effectively. This aligns with previous research (Shuptrine, 2013), which emphasized the unpreparedness of secondary school students for handling complex problems without clear solutions. Therefore, it is crucial to balance the level of complexity and open-endedness to avoid student frustration and disengagement (Doulougeri et al. 2024; Shuptrine, 2013). To avoid this, teachers could for example introduce complexity gradually. That is, to get students used to working with sustainability issues, start with smaller, structured challenges to build students' confidence and familiarize them with the CBL process. In addition, it is important to focus on the learning process rather than the final product, as some challenges may not produce actionable solutions, especially in SE. This helps to prevent demotivation by encouraging reflection, self-assessment, and recognition of student progress and effort. This need for balance also presented difficulties for teachers, acting as coaches, in providing scaffolds for student learning while balancing autonomy and structure. These teachers risked either compromising students' autonomy or leaving them feeling lost without proper support. To address these difficulties, processes should be presented in an organized manner to avoid overwhelming students with new information at the beginning of a CBL project, especially considering their limited exposure to such complex, real-world challenges (Shuptrine, 2013). For example, milestones are often used to break down tasks into smaller, more manageable steps (Iwatani et al. 2020).

Furthermore, in addressing curricular demands, teachers faced difficulties in balancing disciplinary content knowledge with citizenship skill development through CBL, questioning the suitability of CBL for content acquisition. This is not surprising, as teachers typically prioritize content acquisition, considering its relevance for exam success. Furthermore, when considering CBL as an approach to sustainability education requiring curriculum integration, nuances concerning its appropriateness must be taken into account. There are instances when other approaches may be more suitable for knowledge acquisition than CBL, especially when time is

limited and a significant amount of information needs processing. Research has indicated that hybrid approaches, incorporating both student-directed methods and teacher-directed activities such as direct instruction, are most effective in supporting student learning (de Jong et al. 2023). For example, as demonstrated in one study, providing mini-challenges for knowledge transfer proved beneficial for knowledge acquisition (Iwatani et al. 2020).

However, it should be noted that although curricula usually demand uniform learning outcomes, flexibility in learning goals is essential for pursuing CBL-related learning gains, given its student-centered and open-ended nature. To navigate this, and also as a response to ensuring a certain level of knowledge acquisition, teachers could incorporate a frontloading phase in which students first acquire necessary content knowledge through more teacher-directed activities, followed by a CBL project in which students apply and deepen their understanding through inquiry.

Furthermore, expanding on curricular demands, teachers often encountered logistic and educational problems in CBL implementations. For example, teachers experienced little opportunity for cross-curricular activities such as brainstorming sessions or other collaborative activities with colleagues. These problems frequently stemmed from an overload of educational tasks or constraints imposed by curricular demands. Time constraints were also significant, as teachers did not receive additional hours to co-create multidisciplinary education. One explanation for these difficulties lies in the positioning of CBL implementations within the curriculum. Whether structured within the curriculum or as a more project-based approach, most CBL implementations were often situated on the periphery, functioning as interventions outside of core curricular activities, aligning with a bottom-up approach (Doulougeri et al. 2024; Malmqvist et al. 2015). These findings coincide with previous studies highlighting logistic and pedagogical difficulties that limit multidisciplinary education within SE settings, particularly due to tightly compartmentalized curricula that leave little room for cross-curricular activities (Nixon et al. 1999; Taylor et al. 2019). Besides logistic obstacles such as CBL's multidisciplinary approach, its cumulative impact on an already overloaded curriculum is also influenced by ESD's positioning within the school curriculum, which frequently shapes CBL implementations. Currently, sustainability is often seen as an addition to existing structures, overloading teachers. However, research has suggested that ESD could redefine curriculum approaches (Jucker, 2011; Selby, 2008; Sterling, 2004), implying the need for a fundamental shift in school vision and strategy to effectively integrate CBL for sustainability education and raise awareness schoolwide. Therefore, schools must carefully consider the role of sustainability education and CBL within curricula, potentially reallocating time and fostering interdisciplinary collaborations (Taylor et al. 2019).

In addressing the logistical and educational problems—namely, the lack of cross-curricular opportunities for CBL, ESD's positioning on the periphery of the curriculum, and the need for a flexible approach to using CBL within an inflexible curriculum—a PLC within the school could provide pathways to navigate these obstacles. A PLC can foster structured collaboration and shared ownership among teachers while also creating opportunities to work more closely with school leadership. In this study, the CBL projects represented initial efforts by teachers, serving as a foundation for the eventual integration of CBL into the school curriculum. Building on this foundation, and given the autonomy of schools to shape their own education, as well as teachers' enthusiasm for CBL in ESD, teachers, together with school leaders, could explore the next steps for ESD integration. For example, they could (1) explore existing ESD approaches in the Netherlands, such as eco-schools or energy schools; (2) create new subjects that facilitate the integration of CBL and ESD; (3) organize project weeks in which students work on sustainability issues within a CBL context; or (4) set aside time throughout the year for working groups where teachers can meet to discuss CBL opportunities in a cross-curricular setting. This collaborative approach should align with the school's vision and include a well-designed implementation plan by teacher teams to ensure sustainable support and integration across subjects. Moreover, while further research is needed to refine and validate the CBL compass, this tool, tailored to SE, has the potential to help teachers and school leaders map their CBL implementation and guide improvements.

These strategies, which can be seen as an upscaling of teachers' initial efforts, could address many of the challenges highlighted in this study, with the PLC serving as a mechanism to facilitate this upscaling. Furthermore, a cross-school PLC could also specifically contribute to knowledge exchange between schools that would broaden their perspectives on curriculum design, using partnerships to combine resources and address shared challenges. Thus, while the school's autonomy in curriculum design presents many possibilities that might be overwhelming and not suitable for every school, a within and cross-school PLC provides an ideal setting for teachers and school leaders to come together and co-create CBL for ESD approaches that can be distributed and integrated on a larger scale within and across schools.

### *Limitations and future research*

We utilized an adapted CBL compass for secondary education to capture CBL implementations thoroughly, based on literature in secondary education and expert reviews. However, we conceptualized the compass according to our understanding, primarily based on the Dutch educational system. Other researchers could adapt it in different ways based on other educational systems or conceptualizations. Future research could explore the potential implementation of the CBL compass in educational contexts beyond the Dutch system.

In addition, in our conceptualization, we might have overlooked certain CBL characteristics due to teachers' perceptions or awareness gaps (Cohen et al. 2007; Markula & Aksela, 2022). Nevertheless, our participants, although relatively new to CBL, likely included what they considered important. Thus, while our identified characteristics may not be exhaustive, they represent the most significant ones.

Furthermore, considering the perceived successful integration of CBL with ESD by teachers in this study, it is crucial to acknowledge their pioneering results. However, when broader groups of teachers engage with CBL, new difficulties may emerge. For future research, it would be valuable to investigate, through a longitudinal study, the long-term effects of PLCs in promoting sustainable CBL practices for ESD, particularly as a mechanism for overcoming obstacles and scaling-up innovation.

## Conclusion

This study contributes to the body of knowledge on CBL implementations, specifically in the SE context of ESD. The results identify different ways of implementing CBL, with most schools choosing to showcase real-life and meaningful challenges, connecting with students' interests rather than having a challenge owner. Other forms of external collaboration, such as expert interviews, are used instead to ensure authenticity. In the context of ESD, across the diverse range of CBL implementations, CBL proves to be an effective approach and an opportunity for teaching ESD in Dutch SE, as many teachers emphasize the development of citizenship skills vital for addressing sustainability issues. Teachers observe increased enthusiasm and curiosity among students when they were able to explore their own interests within the context of sustainability-related challenges, positively influences their behavior and attitudes toward sustainable development. However, despite the promising outcomes of CBL for ESD, certain facilities are not yet in place, and support structures are still developing, given the early stages of such implementations. Furthermore, CBL implementations for ESD are often superficial and positioned at the periphery of the school's curricula, emphasizing the need for significant changes to fully integrate CBL into the curriculum. These changes primarily relate to curriculum reform, considering the overloaded school curricula, inflexible learning outcomes, and limited opportunities for cross-curricular collaboration. To achieve full integration of ESD, teachers should work closely with school leadership, for example, through a PLC, to explore and redesign the curriculum. This

could include becoming an ECO school, creating a new ESD-related subject using CBL, organizing project weeks, or involving more teachers in the school. In addition, the CBL compass, tailored to secondary education, could help teachers and school leaders map their CBL implementation and inform next steps, further supporting scaling-up efforts. These findings can help educators navigate the complex landscape of CBL implementations and address curricular difficulties within SE, promoting collaboration with school leadership to integrate ESD through CBL.

## Acknowledgements

We extend our gratitude to all the teachers who agreed to participate in this study for data collection, those involved in the professional learning community and especially those who took the time for additional interviews. Full responsibility for this text lies with the authors.

## Ethic approval

On October 30, 2023, this study was approved by the Ethical Review Board (ERB) of the Eindhoven University of Technology. Reference number: ERB2023AP5. Participants signed informed consent describing data collection methods, data management and anonymization of all personal data according to the ethical guidelines of the ERB.

## Disclosure statement

We have no known conflict of interest to disclose.

## Funding

This work was supported by the Netherlands Initiative for Education Research (NRO) under Grant 40.5.23961.020.

## Notes on contributors

***Bart Schutte***, a PhD student at Eindhoven School of Education (ESoE), focuses on implementing challenge-based learning for sustainability education in secondary schools. Bart has experience as a secondary school biology teacher and holds a master's degree in Educational Sciences.

***Annemieke Vennix***, affiliated with ESoE, actively participates as a teacher educator in various collaborative partnerships for teacher training. She brings extensive experience in developing and researching education with external partners, having previously worked as a secondary school teacher and co-authored a physics textbook for Dutch secondary education.

***Jan van der Veen*** is a professor of professional development in science and technology education at the ESoE. He has extensive experience with teacher development teams and curriculum innovation. In 2019, he received a Comenius Leadership Fellowship for advancing interdisciplinary education.

***Dury Bayram*** is an assistant professor specializing in physics education and serves as a teacher educator at ESoE. Her research focuses on socio-scientific issues (SSI), education for sustainable development, citizenship skills, subject didactics, and formative assessment. She has led and participated in diverse projects, including the European ENGAGE project, an NRO project on formative assessment of SSI science lessons, and an Erasmus+project on design education in European teacher training programs.

## ORCID

Bart G. Schutte http://orcid.org/0009-0006-3641-264X
Dury Bayram http://orcid.org/0000-0001-9502-1928
Johanna Vennix http://orcid.org/0000-0001-6295-7471
Jan van der Veen http://orcid.org/0000-0001-5196-6591

## References


Bayram-Jacobs, D., M. Evagorou, Y. Shwartz, and S. Akaygun. 2022. "Science Education for Citizenship through Socioscientific Issues." *Frontiers in Education* 7: 1011576. https://doi.org/10.3389/feduc.2022.1011576.

Boeije, H. 2009. *Analysis in Qualitative Research*. London, UK: Sage.

Borg, C., N. Gericke, H. Höglund, and E. Bergman. 2012. "The Barriers Encountered by Teachers Implementing Education for Sustainable Development: Discipline Bound Differences and Teaching Traditions." *Research in Science & Technological Education* 30 (2): 185–207. https://doi.org/10.1080/02635143.2012.699891.

Castro, M. P., and M. Gómez Zermeño. 2020. "Challenge Based Learning: Innovative Pedagogy for Sustainability through e-Learning in Higher Education." *Sustainability* 12 (10): 4063. https://doi.org/10.3390/su12104063.

Cohen, L., L. Manion, and K. Morrison. 2007. *Research Methods in Education*. 6th ed. New York, NY: Routledge Falmer.

Creswell, J. W. 2003. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. 2nd ed. Thousand Oaks, CA:Sage.

de Jong, Ton, Ard W. Lazonder, Clark A. Chinn, Frank Fischer, Janice Gobert, Cindy E. Hmelo-Silver, Ken R. Koedinger, et al. 2023. "Let's Talk Evidence – The Case for Combining Inquiry-Based and Direct Instruction." *Educational Research Review* 39: 100536. https://doi.org/10.1016/j.edurev.2023.100536.

de Wolf, M., and A. de Hamer. 2015. "Education for Sustainable Development in The Netherlands." In *Schooling for Sustainable Development in Europe*, edited by Jucker, R., and Mathar, R. Vol. 6. Cham: Springer. https://doi.org/10.1007/978-3-319-09549-3_20.

Doulougeri, K., A. A. J. van den Beemt, J. D. Vermunt, M. Bots, and G. Bombaerts. 2022. "Challenge-Based Learning in Engineering Education: Toward Mapping the Landscape and Guiding Educational Practice." In *The Emerald Handbook of Challenge Based Learning*, edited by E. Vilalta-Perdomo, J. Membrillo-Hernández, R. Michel-Villarreal, G. Lakshmi, and M. Martínez-Acosta, 35–68. Bingley, UK: Emerald Group Publishing. https://doi.org/10.1108/978-1-80117-490-920221003.

Doulougeri, K., J. D. Vermunt, G. Bombaerts, and M. Bots. 2024. "Challenge-Based Learning Implementation in Engineering Education: A Systematic Review." *Journal of Engineering Education* 113 (4): 1076–1106. https://doi.org/10.1002/jee.20588.

Fala, J., K. Strouse, C. Tully, and T. Viviano. 2012. *Educating 21st century students: A close-up look at a successful career and technical center*. https://files.eric.ed.gov/fulltext/ED532135.pdf

Fink, L. D. 2003. *Creating Significant Learning Experiences*. San Francisco, CA: Jossey-Bass.

Gallagher, S. E., and T. Savage. 2023. "Challenge-Based Learning in Higher Education: An Exploratory Literature Review." *Teaching in Higher Education* 28 (6): 1135–1157. https://doi.org/10.1080/13562517.2020.1863354.

Gericke, N., A. F. Seiser, A. Mogren, T. Berglund, and D. Olsson. 2024. "How to Institutionalize a Whole School Approach to ESD." In *Whole School Approaches to Sustainability*, edited by Wals, A.E., Bjønness, B., Sinnes, A., and Eikeland, I. Cham: Springer. https://doi.org/10.1007/978-3-031-56172-6_4.

Gruenewald, D. A. 2003. "Foundations of Place: A Multidisciplinary Framework for Place-Conscious Education." *American Educational Research Journal* 40 (3): 619–654. https://doi.org/10.3102/00028312040003619.

Hargreaves, L. 2008. "The Whole-School Approach to Education for Sustainable Development: From Pilot Projects to Systemic Change." *Policy & Practice-A Development Education Review* 6: 69–74.

Iwatani, E., B. Means, M. R. Romero, and M. C. Vang. 2020. *Deepening Science Engagement with Challenge Based Learning: Research Report*. Washington, DC: Digital Promise.

Johnson, L., and S. Adams. 2011. *Challenge Based Learning: The Report from the Implementation Project*. Austin, TX: The New Media Consortium.

Johnson, L., R. Smith, T. Smythe, and R. Varon. 2009. *Challenge-Based Learning: An Approach for Our Time*. Austin, TX: The New Media Consortium.

Jones, M., N. Dailami, E. Weitkamp, D. Salmon, R. Kimberlee, A. Morley, and J. Orme. 2012. "Food Sustainability Education as a Route to Healthier Eating: Evaluation of a Multi-Component School Programme in English Primary Schools." *Health Education Research* 27 (3): 448–458. https://doi.org/10.1093/her/cys016.

Jucker, R. 2011. "ESD between Systemic Change and Bureaucratic Obfuscation: Some Reflections on Environmental Education and Education for Sustainable Development in Switzerland." *Journal of Education for Sustainable Development* 5 (1): 39–60. https://doi.org/10.1177/097340821000500109.

Kopnina, H. 2018. "Teaching Sustainable Development Goals in The Netherlands: A Critical Approach." *Environmental Education Research* 24 (9): 1268–1283. https://doi.org/10.1080/13504622.2017.1303819.

Leijon, M., P. Gudmundsson, P. Staaf, and C. Christersson. 2022. "Challenge Based Learning in Higher Education – A Systematic Literature Review." *Innovations in Education and Teaching International* 59 (5): 609–618. https://doi.org/10.1080/14703297.2021.1892503.

Li, W. T., and P. P. Shein. 2023. "Developing Sense of Place through a Place-Based Indigenous Education for Sustainable Development Curriculum." *Environmental Education Research* 29 (5): 692–714. https://doi.org/10.1080/13504622.2022.2098933.

Luijkx, R., and M. de Heus. 2008. *The educational system of the Netherlands.* https://www.mzes.uni-mannheim.de/publications/misc/isced_97/luij08_the_educational_system_of_the_netherlands.pdf

Malmqvist, J., K. Kohn Rådberg, and U. Lundqvist. 2015. "*Comparative Analysis of Challenge-Based Learning Experiences*." Paper Presented at the 11th International CDIO Conference, Chengdu, Sichuan, P. R. China.

Markula, A., and M. Aksela. 2022. "The Key Characteristics of Project-Based Learning: How Teachers Implement Projects in K-12 Science Education." *Disciplinary and Interdisciplinary Science Education Research* 4 (1): 2. https://doi.org/10.1186/s43031-021-00042-x.

Martin, T., S. D. Rivale, and K. R. Diller. 2007. "Comparison of Student Learning in Challenge-Based and Traditional Instruction in Biomedical Engineering." *Annals of Biomedical Engineering* 35 (8): 1312–1323. https://doi.org/10.1007/s10439-007-9297-7.

Martínez-Acosta, M., J. Membrillo-Hernández, and M. R. Cabañas-Izquierdo. 2022. "Sustainable Development Goals through Challenge-Based Learning Implementation in Higher Education – Education for Sustainable Development (ESD)." In *The Emerald Handbook of Challenge Based Learning*, edited by E. Vilalta-Perdomo, J. Membrillo-Hernández, R. Michel-Villarreal, G. Lakshmi, and M. Martínez-Acosta, 281–299. Bingley, UK: Emerald Group Publishing. https://doi.org/10.1108/978-1-80117-490-920221012.

Mathie, R. G., and A. E. J. Wals. 2022. *Whole School Approaches to Sustainability: Exemplary Practices from around the World*. 1st ed. Wageningen, Netherlands: Wageningen University. https://doi.org/10.18174/566782.

McGorry, S. Y. 2000. "Measurement in a Cross-Cultural Environment: Survey Translation Issues." *Qualitative Market Research: An International Journal* 3 (2): 74–81. https://doi.org/10.1108/13522750010322070.

Membrillo-Hernández, J., M. J. Ramírez-Cadena, M. Martínez-Acosta, E. Cruz-Gómez, E. Muñoz-Díaz, and H. Elizalde. 2019. "Challenge Based Learning: The Importance of World-Leading Companies as Training Partners." *International Journal on Interactive Design and Manufacturing (IJIDeM)* 13 (3): 1103–1113. https://doi.org/10.1007/s12008-019-00569-4.

Menchaca-Torre, H. L., E. Niño-Juárez, A. Y. Vanoye-García, and M. Delgado-Fabián. 2024. "Comparison of Challenge-Based and Problem-Based Learning in Engineering Students' Academic Performance." 2024 IEEE Global Engineering Education Conference (EDUCON), 1–6. https://doi.org/10.1109/EDUCON60312.2024.10578844.

Mogren, A., N. Gericke, and H. A. Scherp. 2019. "Whole School Approaches to Education for Sustainable Development: A Model That Links to School Improvement." *Environmental Education Research* 25 (4): 508–531. https://doi.org/10.1080/13504622.2018.1455074.

Nichols, M., and K. Cator. 2008. *Challenge Based Learning [White Paper]*.Cupertino, CA: Apple.

Nixon, J., K. Sankey, V. Furay, and M. Simmons. 1999. "Education for Sustainability in Scottish Secondary Schools: Boundary Maintenance or Professional Reorientation?" *Environmental Education Research*, 5 (3): 305–318. https://doi.org/10.1080/1350462990050305.

Olson, K. 2010. "An Examination of Questionnaire Evaluation by Expert Reviewers." *Field Methods* 22 (4): 295–318. https://doi.org/10.1177/1525822X10379795.

Rådberg, K., U. Lundqvist, J. Malmqvist, and O. Hagvall Svensson. 2020. "From CDIO to Challenge-Based Learning Experiences – Expanding Student Learning as Well as Societal Impact?" *European Journal of Engineering Education* 45 (1): 22–37. https://doi.org/10.1080/03043797.2018.1441265.

Selby, D. 2008. The need for climate change in education. In J. Gray-Donald & D. Selby (Eds.), Green frontiers: Environmental educators dancing away from mechanism (pp. 252–262). Leiden, The Netherlands: Brill. https://doi.org/10.1163/9789087904654

Shuptrine, C. 2013. "Improving College and Career Readiness through Challenge-Based Learning." *Contemporary Issues in Education Research (CIER)* 6 (2): 181–188. https://doi.org/10.19030/cier.v6i2.7727.

Sobel, D. 2004. "Place-Based Education: Connecting Classroom and Community." *Nature & Listening* 4 (1): 1–7.

Stables, A., and W. Scott. 2002. "The Quest for Holism in Education for Sustainable Development." *Environmental Education Research* 8 (1): 53–60. https://doi.org/10.1080/13504620120109655.

Sterling, S. 2004. "Higher Education, Sustainability, and the Role of Systemic Learning." *Higher Education and the Challenge of Sustainability*, edited by P. G. Corcoran and A. E. J. Wals, 49–70. Dordrecht, Netherlands: Springer. https://doi.org/10.1007/0-306-48515-X_5.

Stoll, L., R. Bolam, A. McMahon, M. Wallace, and S. Thomas. 2006. "Professional Learning Communities: A Review of the Literature." *Journal of Educational Change* 7 (4): 221–258. https://doi.org/10.1007/s10833-006-0001-8.

Sukackė, Vilma, Aida Olivia Pereira de Carvalho Guerra, Dorothea Ellinger, Vânia Carlos, Saulė Petronienė, Lina Gaižiūnienė, Silvia Blanch, Anna Marbà-Tallada, and Andrea Brose. 2022. "Towards Active Evidence-Based Learning in Engineering Education. A Systematic Literature Review of PBL, PjBL, and CBL." *Sustainability* 14 (21): 13955. https://doi.org/10.3390/su142113955.

Taconis, R., and T. Bekker. 2023. "Challenge Based Learning as Authentic Learning Environment for STEM Identity Construction." *Frontiers in Education* 8: 1144702. https://doi.org/10.3389/feduc.2023.1144702.

Takala, A., and K. Korhonen-Yrjänheikki. 2019. "A Decade of Finnish Engineering Education for Sustainable Development." *International Journal of Sustainability in Higher Education* 20 (1): 170–186. https://doi.org/10.1108/IJSHE-07-2018-0132.

Taylor, N., F. Quinn, K. Jenkins, H. Miller-Brown, N. Rizk, T. Prodromou, P. Serow, and S. Taylor. 2019. "Education for Sustainability in the Secondary sector – A Review." *Journal of Education for Sustainable Development* 13 (1): 102–122. https://doi.org/10.1177/0973408219846675.

UNESCO. 2020. *Education for Sustainable Development: A Roadmap*. Paris, France: UNESCO. https://doi.org/10.54675/YFRE1448.

van den Akker, J. 2003. "Curriculum Perspectives: An Introduction." In *Curriculum Landscapes and Trends*, edited by J. van den Akker, W, Kuiper, and U. Hameyer, 1–10. Dordrecht, Netherlands: Kluwer.

van den Beemt, A., G. van de Watering, and M. Bots. 2023. "Conceptualising Variety in Challenge-Based Learning in Higher Education: The CBL-Compass." *European Journal of Engineering Education* 48 (1): 24–41. https://doi.org/10.1080/03043797.2022.2078181.

Vanblaere, B., and G. Devos. 2015. "Exploring School Leadership and Structural School Characteristics in Professional Learning Communities: A Multilevel Analysis. *International Congress for School Effectiveness and Improvement, Abstracts*." Presented at the International Congress for School Effectiveness and Improvement, Cincinnati, Ohia, USA.

Ver Steeg, J. 2019. "Developing a Public Voice: Place-Based Education as an Approach to Education for Sustainable Development in the EFL Classroom." *PUPIL: International Journal of Teaching, Education and Learning* 3 (1): 71–87. https://doi.org/10.20319/pijtel.2019.31.7187.

Waal, M. van der. 2011. "The Netherlands." In *National Journeys towards Education for Sustainable Development*, edited by I. Mulà and D. Tilbury, 77–102. Paris: UNESCO. https://unesdoc.unesco.org/ark:/48223/pf0000192183.

Wesselink, R., and A. E. J. Wals. 2011. "Developing Competence Profiles for Educators in Environmental Education Organisations in The Netherlands." *Environmental Education Research* 17 (1): 69–90. https://doi.org/10.1080/13504621003637037.

Yemini, M., L. Engel, and A. Ben Simon. 2023. "Place-Based Education – A Systematic Review of Literature." *Educational Review:* 1–21. https://doi.org/10.1080/00131911.2023.2177260.

# Appendix A

## *Guiding tool – secondary education CBL compass*

| Element | Dimension | Indicator |
|---|---|---|
| Vision | Real-life open-ended challenges | The extent to which challenges are real-life |
| | | The extent to which challenges are authentic |
| | | The extent to which challenges are open-ended |
| | | The extent to which challenges are complex |
| | | The extent to which challenges cut across disciplines |
| | Global themes | The extent to which challenges focus on transforming business-as-usual practices and raising awareness and trust among actors |
| | | The extent to which challenges enable students to contribute value to their community |
| | Student centered | The extent to which challenges foster self-directed learning |
| | | The extent to which challenges enable students to take ownership of their learning |
| | Involvement of challenge owner | The extent to which challenges have a challenge owner from academia, industry, government, or culture |
| | | The extent to which challenges require collaboration with external stakeholders |
| | Curriculum | The extent to which the challenge aligns with curriculum objectives |
| Teaching and learning | Citizenship | The extent to which learning activities support the development of citizenship skills |
| | Inquiry-based learning | The extent to which materials and learning activities support contextualized acquisition and application of disciplinary knowledge and skills |
| | | The extent to which learning activities allow students to define their own objectives based on their own interests |
| | | The extent to which learning activities foster the inclusion of different perspectives when studying the disciplinary content |
| | | The extent to which learning activities stimulate critical reflection |
| | | The extent to which learning activities support the development of research skills |
| | | The extent to which learning activities support the development of meta-cognitive skills and self-regulatory abilities |
| | | The extent to which learning activities enable dealing with uncertainty |
| | Collaborative learning | The extent to which learning activities stimulate cycles of divergent and convergent reasoning within a team |
| | | The extent to which learning activities emphasize interdependence among team members |
| | | The extent to which learning activities promote peer learning |
| | Assessment | The extent to which assessment includes both the process and the products |
| | | The extent to which assessment takes into account both individual and team contributions to the learning process |
| | | The extent to which assessment integrates both formative and summative assessment |
| | Teaching | The extent to which coaching supports scaffolding of students' learning |
| | | The extent to which teachers allow students autonomy while also providing support and scaffolding |
| | | The extent to which teachers can act as coaches, co-learners and co-creators |
| | | The extent to which teacher prompts/guidance are focused on the content space at the meta-level (e.g. giving feedback on students' strategies or helping students plan their task progress) |
| | | The extent to which teacher prompts/guidance are focused on the relational space (e.g. giving feedback on students' collaboration process or helping students resolve conflicts) |
| | | The extent to which teachers collaborate across disciplines |
| | Learning technology | The extent to which learning activities integrate technology, allowing students to use tools effectively for learning and problem-solving |

Appendix A (continued)

| Element | Dimension | Indicator |
|---|---|---|
| Support | Facilities | The extent to which facilities offer required materials for both the development and implementation phases |
| | | The extent to which facilities offer required spaces for both the development and implementation phases |
| | | The extent to which facilities offer required time for both the development and implementation phases |
| | | Facilities offer required tools, including ICT, for both the development and implementation phases |
| | Teacher support | The extent to which support structures offer course design and pedagogical support for teachers |
| | | The extent to which support structures guide teachers in developing coaching skills and other teaching skills required in a CBL context |

# Appendix B

## *Descriptions of CBL projects*

| Project | Description CBL projects |
|---|---|
| EcoKino | This project spanned 13 lessons and was integrated into the biology curriculum on ecology, where students chose a subdiscipline from population ecology, community ecology, or ecosystem ecology. Students explored these topics through local and global case studies, identifying a global issue related to their chosen topic and refining it into a challenge. In general, the challenge was to create an artistic project that raised awareness of a sustainability issue affecting ecosystems. For example, sustainability issues included meat production and deforestation, the extinction of wild bees, and palm oil production in Asia. After formulating their challenge, students investigated their issues through research and interviews with two external stakeholders. They then translated their science into a cinematic project that emphasized value and emotion – options included a video, photo series, song, play, or podcast. |
| Sierra Leone | This project spanned an entire semester, during which students worked weekly on a topic related to the SDGs, such as gender equality, clean water, or no poverty. Students began by selecting an SDG that interested them, and then refined their focus into a specific challenge. In general, the challenge was to build meaningful connections with Sierra Leonean peers to collaboratively explore and address an issue related to the SDGs. For example, students explored issues such as access to clean water or gender equality. Throughout the project, students engaged in personal dialogue with their Sierra Leonean peers through letter writing, asking and answering questions about their chosen topics. In addition, students worked in groups to create reflective mind map posters and multimedia projects, such as videos or presentations, that expressed how their chosen SDG was understood in both local and global contexts. The final products were shared with peers in both countries, promoting cross-cultural learning and awareness. |

Appendix B (continued)

| Project | Description CBL projects |
|---|---|
| Amstory | This project spanned three class periods and was integrated into the art, career exploration, and geography curricula. Students were required to write a reflective report that was included in their art portfolio, along with a separate assignment for geography. The project lasted about a month and a half and included a trip to Amsterdam, followed by an innovation fair attended by both teachers and external stakeholders. The big idea of the project was an urban sustainability, approached from a selected perspective related to the SDGs. The challenge was clear: make Amsterdam sustainable by 2030. Students could choose from a variety of perspectives, including tourism, employment, inclusivity, health, and waste management. After the research phase, students traveled to Amsterdam to interview key stakeholders relevant to their research. Proposed solutions were diverse, ranging from adding more bins at tourist hotspots for better waste management, to introducing a Dutch license for cannabis sales to control tourism, to promoting other Dutch cities to reduce the tourist burden on Amsterdam. |
| Green badge | This project spanned approximately 8 wk and was implemented in the English Language Learning Department, where there was no set curriculum and teachers were free to design their lessons. The main objective was to help students navigate language use within the school. During the project, students focused on four themes derived from the SDGs: waste management, greening, water conservation, and food sustainability. Each group selected one theme to research and develop a solution. The big idea focused on creating a sustainable campus, framed by the essential question: How can we help the eco-school earn the green badge? The challenge was tailored to one of the four themes. Throughout the project, students formulated their challenge, conducted interviews with the Eco-School team, and were encouraged to articulate the rationale behind their proposed solutions while outlining clear action plans for implementation at the school. |
| Sustainable campus | This project spanned an entire academic year and was integrated into the physics curriculum, where students worked on the overarching challenge of creating a more sustainable campus for their school. The project began with students learning about the SDGs, exploring where these goals intersected with their own lives, and understanding how they could influence change. They then explored the school campus to identify key areas for improvement, with five themes selected, such as temperature, waste management, and noise. Within these themes, students were free to choose their focus. In addition to the main challenge, mini-challenges were incorporated to meet specific curriculum objectives. At the end of the project, students presented their findings and solutions to the school board and participated in a science fair for teachers and parents. Solutions include Reducing CO2 emissions through an alternative bus schedule for students, an innovative solution for solar panels considering the school's heritage status, and setting up an awareness campaign for waste around the school with monthly activities. |
| ASM | This project spanned approximately 9 to 12 lessons within the physics curriculum. The big idea of the project was geophysics, with a focus on extreme weather phenomena such as hurricanes, extreme rainfall, and droughts. The challenge was to design a research proposal rather than doing the entire research. This approach encouraged students to formulate research questions, select relevant physics concepts, and connect them to real-world climate challenges related to the SDGs. Students had the freedom to choose one of four routes related to extreme weather events. |

Appendix B (continued)

| Project | Description CBL projects |
|---|---|
| Sustainable energy | This project spanned about 8–10 lessons within the physics curriculum. The big idea focused on affordable and clean energy (SDG 7), with the essential question: How should the energy challenges of the future be addressed? This project integrated both CBL, the Scrum methodology, and the physics topic of energy, allowing students to explore sustainability within the context of their subject matter. Rather than a completely open-ended investigation, the project was tied directly to the energy chapter in the curriculum, allowing students to investigate real-world energy issues while still meeting key learning objectives. They were tasked with breaking down the big question into smaller, more manageable components, conducting research, and proposing solutions to future energy challenges. The project concluded with each group presenting their research and proposed solutions. |
| Disability tool | This one-week project was part of the MAVO Challenge Program (MCP), an initiative linked to the Bèta Challenge Program. The overall idea was to provide students with hands-on, project-based learning that addresses real-world needs. Based on the theme of health and wellness, the challenge was to design a functional aid for people with disabilities in collaboration with the local disability platform. Students were tasked with creating assistive devices for people with various disabilities, such as visual or hearing impairments. They were given the freedom to brainstorm, design and prototype their solutions from scratch. To increase real-world relevance, the project included direct stakeholder engagement – members of the Disability Platform visited the school to evaluate the students' creations. The project culminated in a presentation where each group demonstrated their prototypes to the visiting stakeholders. One notable solution was a planning board developed for people with dementia, inspired by a student whose mother worked in a nursing home for dementia patients. |

# Appendix C

## *Codebook*

| Element | Category | Codes |
|---|---|---|
| Vision | Real-life open-ended challenges | Real life |
| | | Open-ended |
| | | Complex |
| | | Authentic |
| | | Across disciplines |
| | Global themes | Transformative and integrative value |
| | | Contribution |
| | Involvement of challenge owner | Challenge owner |
| | | External collaboration |
| | Student-centered | Self-directed learning |
| | | Ownership of learning |
| | | Student interests* |
| | | Meaningful learning* |
| | Curriculum | Curriculum alignment |

Appendix C (continued)

| Element | Category | Codes |
|---|---|---|
| Teaching and learning | Citizenship | Citizenship skills |
| | Inquiry-based learning | Disciplinary knowledge and skills |
| | | Own objectives and interests |
| | | Different perspectives |
| | | Critical reflection |
| | | Research skills |
| | | Meta-cognitive skills |
| | | Uncertainty |
| | Collaborative learning | Divergent and convergent reasoning |
| | | Interdependence |
| | | Peer learning |
| | Assessment | Process and product |
| | | Individual and team |
| | | Summative and formative |
| | Teaching | Coaching supports scaffolding of learning |
| | | Autonomy and scaffolding – clarifying complexity** |
| | | Autonomy and scaffolding – Differentiation teacher-regulation** |
| | | Autonomy and scaffolding – Autonomy within structure** |
| | | Teacher role as coach |
| | | Support on content level (e.g. feedback on students' strategies) |
| | | Support on relational space (e.g. feedback on students' collaboration process) |
| | | Collaborate across disciplines |
| | Learning technology | Integrating technology |
| Support | Facilities | Materials |
| | | Spaces |
| | | Time |
| | | Tools |
| | Teacher support | Coaching and teaching skills |
| | | Design and pedagogical support |
| | | Backing (support from colleagues)* |
| Teachers' views and experiences | Experiences | Challenges |
| | | Successes |
| | Views | Opportunities for project development |
| | | Relation to sustainability education* |

*Note*. *New codes that emerged through the coding process. **Subcodes.