Variety in Challenge-Based Learning in higher education

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VARIETY IN CHALLENGE-BASED LEARNING IN HIGHER EDUCATION

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ABSTRACT

Increasingly higher education programs are made open and flexible to face challenges demanded by societal changes. Challenge-based learning (CBL) is perceived as an educational concept shaping these open and flexible programs. However, CBL as a field of research is still in its infancy. The present study searches for all-embracing commonalities of CBL in engineering education. We propose an evaluative framework that both includes commonalities and allows for variety in CBL characteristics between study components. This framework, labelled CBL-compass, serves as a methodological approach for educational staff and researchers to visualise the local colour of CBL in higher education institutions. With this study we aim to advance the field by contributing to a conceptual basis in flexibility in CBL. Our research question was: How can we assess the variety of CBL implementations in engineering education experiments? This question was answered by an evaluative case study. First, existing literature on CBL was scoped. The characteristics following from this review were perceived as dimensions, each with associated indicators. Empirical data were collected from an evaluation of six CBL experiments. The variety of scores on the CBL-compass gave an impression of how teachers implemented CBL in their course or project and can thus be used as an evaluation mechanism to improve this implementation. Filling in the CBL-compass triggered

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reflection among teachers about their course and CBL. The added value of the CBL-compass is the attention for, amongst others assessment or teacher skills and support, which are important for the overall quality of study components.

1 INTRODUCTION

In Challenge-based learning (CBL) challenges are seen as self-directed work scenarios in which students engage [1]. The goal of these challenges is to learn how to define and address the problem and to learn what it takes to work towards a solution, rather than to solve the problem itself. The final deliverable can be tangible or a proposal for a solution to the challenge [2].

The present study searches for all-embracing commonalities of CBL in engineering education. The use of commonalities might suggest that CBL implies implementation of a full-fledged version of challenges. However, because educational practice aims to stimulate and facilitate students' development, the need arises to allow for different forms of challenges. Therefore, we aim for a framework that both includes commonalities, and allows for variety in CBL characteristics between study components or curricula. This framework can serve as a methodological approach to make engineering education (more) CBL [3].

Existing literature shows a limited understanding of this variety in CBL characteristics, and how it affects research and educational development. This paper addresses this gap in knowledge by bringing together evidence informed characteristics of CBL, and second, use these principles to evaluate a set of exploratory projects initiated at university [blinded], in the Netherlands. We propose an evaluative framework, to be used by teachers, teacher supporters, and researchers to visualise the local colour of CBL in higher education institutions. It contributes to a conceptual basis in flexibility [3], needed to inform debate and development in a field of research that is still in its infancy.

1.1 CBL as an educational concept

CBL in our perception is an educational concept, rather than a teaching method (see also [1]). Educational concepts can be defined as views on what is worth learning and how students should acquire that learning [4]. Educational concepts underscore a complex set of educational practices that ask for a specific organisation. These practices include vision and support, but above all teaching methods, which in turn can be defined as the principles and activities used by teachers to enable student learning.

If universities intend to use CBL as a concept for the complete curriculum, a developmental perspective is needed, which implies a variety in CBL characteristics across study components. Furthermore, we argue for a fine granulated view on CBL, including for instance active learning, deep learning to develop meta-cognitive skills, and self-regulatory abilities [5][6]. More specifically for engineering education, aspects such as systems thinking, entrepreneurial thinking, or working in an iterative cyclical way can be added [7].

To guide the analysis of variety in CBL, we propose a framework in two parts: a high-level conceptual framework, and for each concept a set of accompanying dimensions and indicators. The high-level concepts allow to identify educational processes at the three levels of vision, teaching and learning, and support [7][8]. Vision serves as a foundation for the implementation of CBL by describing the basic motivations and goals governing an educational program. Teaching and learning include curricular aspects such as learning goals, design of instruction, coaching and assessment. Teaching thus puts vision into action, with learning as a mutually enforcing parallel process. Teaching and learning processes depend on conditions and resources being in place that facilitate their development and operation. Support consists of aspects such as infrastructure and institutional support, tools and techniques, and resources for developing teacher skills.

Our exploration of CBL characteristics across study components was guided by the following research question:

How can we assess the variety of CBL implementations in engineering education experiments?

To address this research question in a real-life context, we selected six educational experiments carried out at university [blinded]. We answer our research question by bringing together commonalities of CBL on the levels of vision, teaching and learning, and support.

2 METHODOLOGY

To understand the CBL-compass as a tool for visualising variety in CBL implementations, an evaluative case study method was chosen. The context for the current case study is an extensive educational innovation initiative focused on large-scale development, implementation, and evaluation of CBL at a Dutch university of technology.

2.1 Data collection

First, existing literature on CBL was scoped using search engines and referrals from relevant articles. Included were seminal CBL defining studies, derived from queries in Google Scholar and Web of Science, and snowballing the resulting articles for other often cited sources. The intention was a grounded overview of characteristics of CBL, rather than an exhaustive literature review.

The characteristics following from this review were ordered on the three levels of the higher-order conceptual framework. These characteristics were perceived as dimensions, each with associated indicators. All indicators draw on four-point Likert-scale items (Not implemented - 1; To some extent - 2; To large extent - 3; Fully implemented - 4) indicating evidence of the characteristics.

Subsequently, empirical data were collected from meetings, and evaluation of six experiments focused on CBL. Each of these experiments were considered to represent the university's purpose in its own way, and included courses showing a variety of CBL implementations. In collaboration with responsible teachers the level of CBL implementation was assessed using the grounded overview of CBL characteristics derived from existing literature.

3 RESULTS

3.1 Framework description

Existing literature shows that CBL most often is perceived as an additional pedagogical approach to existing structures [3]. In contrast, our university aims at CBL as embedded curriculum practice. This large-scale curriculum approach, in combination with research intends to contribute to the current limited body of evidence for mechanisms that cause CBL interventions to be effective.

3.2 Variety of perceptions of CBL

Following existing literature of CBL and engineering education, and overarching educational characteristics such as active learning and deep learning, a set of dimensions and indicators of CBL can be discerned. Our argument is not that all indicators are fully present in every project or course. Rather, we expect a variety of designs and perceptions of CBL to be found in current and future study components. To depict this variety, we consider the CBL dimensions, and on a more granulated level indicators for each dimension, as 'sliders' that can be adjusted following the study component's definition of CBL and intended learning gains. These sliders measure personal reflections of teachers or curriculum designers, on the level of CBL implementation.

3.3 Dimensions and indicators

The dimensions and indicators below are categorised following the higher order model of vision, teaching and learning, and support. The (intended or observed) presence of individual indicators in experiments can be set with a slider representing the extent of their presence.

Vision

Real-life open-ended challenges

CBL focusses on relevant real-life, authentic, open-ended challenges to trigger learning. These challenges can be mono- and interdisciplinary, originating from various sources (problems/challenges trigger learning) [9]. Authentic here refers to resembling or being derived from the activities of real-world professionals (see also [10]) to allow also for challenges that could emerge in the future. Open-ended assignments are common in engineering education because engineering design is open-ended with respect to both the solution and the process [11]. Open-ended challenges allow students to discover both a problem and a solution, allowing varying solution paths [12].

Global themes

Thematic content areas addressed in CBL are predominantly rooted in themes of global importance, such as sustainability [3]. In that respect CBL is value-driven, with a focus on transformative value and integrative value [13][14]. Transformative value is perceived as outcomes that challenge business-as-usual practices understood as unsustainable. Integrative value can be described as awareness raised and trust built when a diverse group of actors, disciplines, and perspectives are brought together in dialogue to explore a common issue. Both types of value can have either a short-term or long-term societal impact, of which students need to be aware.

Involvement of stakeholders

CBL engages students by involving stakeholders from science, industry, or the societal context [14]. A distinction can be made between 1) university developed challenges, reflecting little collaboration with external stakeholders, and 2) challenges brought and actively supported by stakeholders [15].

Teaching and learning

T-shaped engineers

Engineering education has long emphasized metacognitive abilities such as systems thinking, and T-shape competencies, in which an in-depth disciplinary expertise is coupled with the ability to work with a broad range of people and situations [16][7]. CBL challenges educators to present learning activities that contribute to an in-depth disciplinary expertise, by creating a rigorous treatment of engineering fundamentals [14]. Furthermore, innovation and creativity are considered important aspects in many CBL cases [3]. This can be operationalised in critical thinking (see also [17][18]) and creative thinking [19]. Finally, CBL is characterized by a combination of problem formulating and designing, which implies working in an iterative cyclical way, involving both analysis and synthesis [9].

Self-directed learning

CBL creates a learning urgency, by encouraging students to both acquire and apply knowledge and skills that are needed to work on a specific challenge, which makes their learning contextualised (e.g., [20]). The materials and learning activities will be different for each student, thus enhancing student participation in conceiving and defining their own pathway in learning, also known as 'learning trajectories' [21].

CBL fosters deep learning by supporting the development of metacognitive skills. CBL is also active learning that allows students to construct a network of knowledge and take ownership (agency) of their own learning process (self-directed learning), including the freedom to choose within a broader challenge the specific problem they want to focus on [22]. Active learning is perceived as an approach that creates student engagement with learning materials through interactions such as reading, watching, listening, writing, analysing, experimenting, and thinking [23][6]. Agency and Self-directed learning also include an entrepreneurial mindset, which finds ways to deal with uncertainty [24] and open-endedness.

Assessment

CBL stimulates forms of assessment between product focused assessment and process focused assessment. In product focused assessment the deliverable represents what is learnt in terms of content knowledge and understanding, and the mastery of real-world skills [25]. Process focused assessment evaluates whether the knowledge and skills have been obtained. The balance between these two stands for the extent to which intended learning behaviour becomes visible in both product and process [26]. Gallagher and Savage (2020) show how different approaches to CBL lead to a variety in assessment, especially regarding (in)formative and summative assessment, and assessment of individual and team involvement. Balancing also these forms of assessment implies that CBL aspects such as team progress, interdisciplinarity, and advanced knowledge and skills are evaluated during regular checkpoints with teams and individuals [25].

Teaching

CBL involves adaptive teacher and expert guidance of construction of knowledge by students. Students need scaffolding towards content (also known as clear signposting), and towards active learning [1][27][28]. Yet, given the level of open-endedness and complexity of challenges, teachers are suggested to find a balance between openness and scaffolding. It appears that this balance is easier to be found when teachers act as coaches and co-learners and co-creators (cf., [29][30]).

Collaborative learning

CBL means working in an iterative cyclical way in teams [31][10]. These cycles consist of divergent and convergent reasoning bringing students closer to possible solutions to the challenge. Divergent reasoning includes a variety of perspectives and solutions, while convergent reasoning brings focus and priority to this variety. Ideally these cycles are discussed and evaluated in groups, which in turn enables room for peer feedback and support.

Interdisciplinarity

Interdisciplinary CBL facilitates students from different (sub-)disciplines to learn to work in a team. Their interdisciplinary interactions can be seen as attempts to integrate heterogeneous knowledge bases and knowledge-making practices [32]. Interdisciplinarity thus requires some level of integration between fields of expertise [33]. Individuals in interdisciplinary teams learn from others' perspectives and produce work in an integrative process that would not have been possible in a mono-disciplinary setting [34]. The result, at least in theory, is that participants emerge from such interactions speaking “one language” [7].

Learning technology

Because the nature of CBL presumes extensive access to technology [35], technology rich learning environments lend themselves to support learning aspects of CBL such as active learning, deep learning, social learning, and learning analytics [1][3]. Especially for engineering education, learning technology plays a key role in learning processes, for example with simulators and virtual labs, and is also often a product of this learning [36].

Support

Facilities

CBL involves facilitation of learning and teaching in terms of required materials, spaces such as classrooms or laboratories, and tools including ICT [37][38]. Especially the combination and alignment of physical and online facilities is reported as important by stakeholders [39].

Teacher support

CBL involves support for teachers and tutors, not only on the design of challenges and related learning activities, but also in dealing with uncertainty, and in their shift from content expert to being both expert and coach [2].

4 FRAMEWORK APPLICATION AND VISUALISATION

For each course included in the sample of experiments the score on CBL dimensions and indicators was calculated. We found a variety of scores, with the largest between-experiment variance on the dimensions 'Self-directed learning', 'Teaching', and 'Interdisciplinarity'. This indicates a variety among teachers on their perceived roles and how they guide and support students. Between-experiment variances on other indicators were usually explained by teachers as deliberate choices within their specific course or project.

The resulting scores were visualised in a radar-graph (see Figure 1). This visualisation immediately triggered teachers to reflect on different aspects of their course, and how they could 'make it more CBL'. During the interviews it was emphasised that the resulting image is a perception rather than a value judgement on the level of CBL in a specific course.

4.1 Vision

We examined the extent to which challenges were relevant to 'Real-life open-ended challenges', 'Global themes', and 'Involvement of stakeholders'. The indicator 'Real-life and authentic', considered as a 'must have' was perceived as largely or fully implemented in most courses. The other indicators under this dimension, 'open-ended', 'complex' and 'interdisciplinary' showed a more diverse image. The dimensions 'Global themes' and 'Involvement of stakeholders' also showed variety between courses. When asked for the level of implementation, teachers responded that it either was on purpose, or that it was an aim for future course development to implement these dimensions to higher levels.

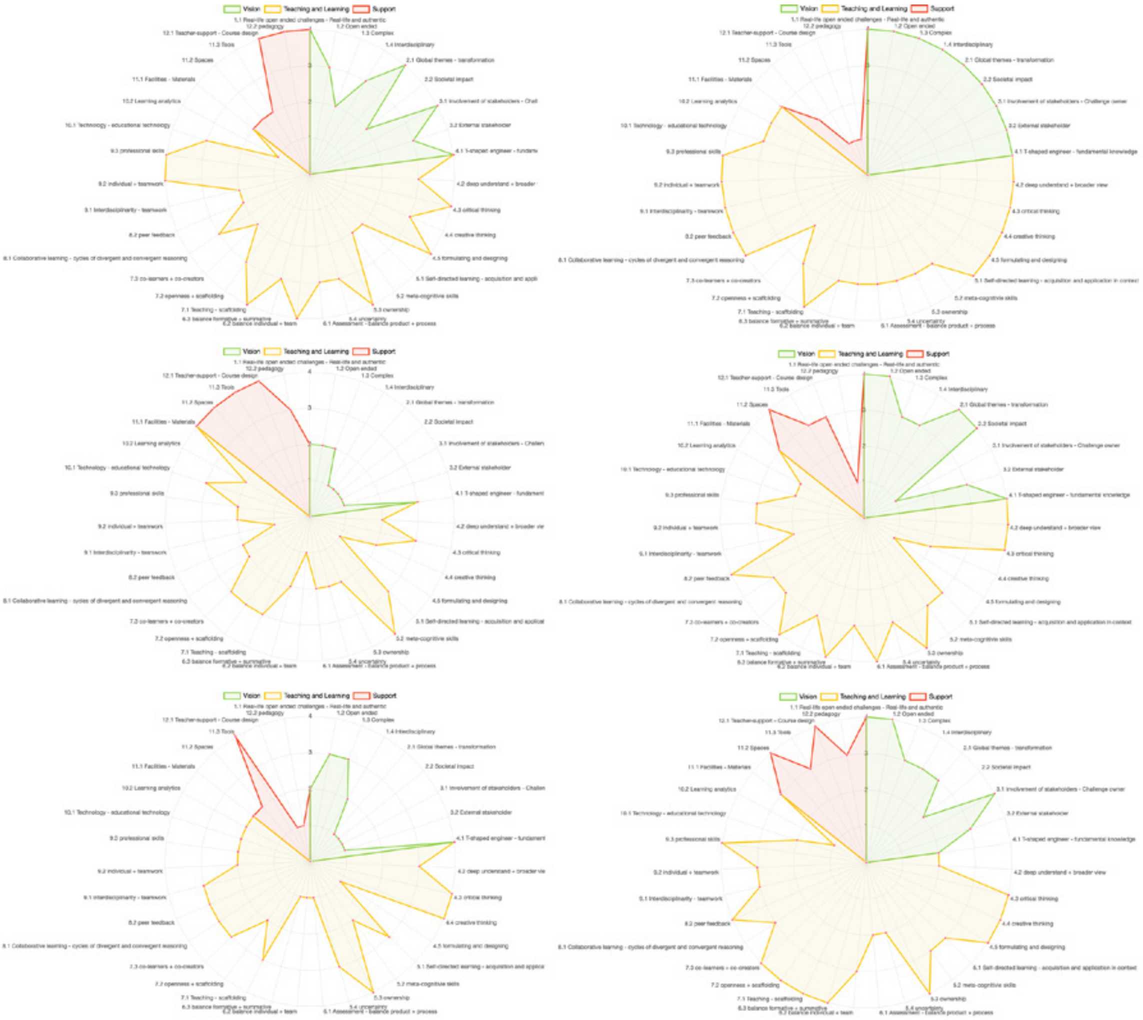

Fig. 1. CBL-compass results for six courses

4.2 Teaching and learning

The indicators under 'T-shaped engineers' scored unevenly: 'Rigorous treatment of discipline knowledge received in general high scores. Teachers reported it as a 'must have', with the only exception being a project focussing on entrepreneurship and interdisciplinary teamwork. The second indicator of this dimension, 'Combining a deep understanding and broader view' received moderate to high scores. All indicators under the dimension 'Self-directed learning' were addressed, however with a disharmonic result across courses: not all indicators were addressed evenly and not all indicators at the same level within a course. Teachers reported on 'Self-directed learning' that their aims were high, however, in their perception students were often not able to reach the intended levels.

Scores on the dimension 'Assessment' were influenced by the perceived level of balance on all three indicators. Teachers explained how they perceive their score as an encouragement to bring more balance to assessing process and product, individual and teamwork, and formative and summative assessment. Furthermore, although teachers reported to go to large extents in scaffolding students, they in general did not consider themselves as co-learners or co-creators of solutions.

4.3 Support

The indicators under support provoked strong responses by teachers. They responded either highly positive about each of these dimensions, or highly negative. Teachers explained their response being related to perceived support on a university level, either in terms of materials or in terms of pedagogical support.

5 DISCUSSION AND CONCLUSION

This study explored an analysis and visualisation of the variety of CBL characteristics within and between study components in an academic engineering curriculum. The aim was an evaluative framework, to be used by teachers, teacher supporters, and researchers to visualise the local colour of CBL in higher education institutions.

The variety of scores on the CBL dimensions and indicators in the CBL-compass, together gave an impression of how teachers implemented CBL in their course or project. More importantly, filling in the CBL-compass triggered a constructive dialogue and reflection among teachers about their course and about the degree to which CBL principles were implemented. In general, they expressed a developmental perspective, with low scoring indicators as starting points for future work. Furthermore, with CBL being visualised for a growing number of study components a finer granulated view of indicators will appear.

Researchers could use the CBL-compass to systematically evaluate the variety of CBL implementation across study components. The question behind each combination of values for CBL characteristics would be "what do students gain from this specific CBL approach?" Furthermore, a related question is "which learning mechanisms need to be activated with CBL?". Further research could detail distinctive CBL characteristics of courses, which scored highly on some of the indicators, identifying patterns in these indicators.

The instrument proposed in this study supports faculty and educators in their design of CBL courses and projects. The CBL-compass can be integrated into course and curriculum design processes as an evaluation mechanism to improve implementation of CBL. The added value over existing frameworks is the attention for, amongst others assessment or teacher skills and support, which are important for the overall quality of study components. Using the CBL-compass presented in this paper in conjunction with for instance design principles would broaden the evaluation of CBL implementation and thus strengthen CBL as an educational concept. The dimensions and indicators of the CBL-compass are fundamental characteristics of CBL. However, the CBL-compass is considered a living tool that grows with CBL implementation to reflect the local colour of CBL.

REFERENCES

[1] Johnson, L. F., Smith, R. S., Smythe, J. T., Varon, R. K. (2009). *Challenge-Based Learning: An Approach for Our Time.* Austin, Texas: The New Media Consortium

[2] Membrillo-Hernández, J. & García-García, R. (2020). *Challenge-Based Learning (CBL) in Engineering: which evaluation instruments are best suited to evaluate CBL experiences? 2020 IEEE Global Engineering Education Conference (EDUCON)*, Porto, Portugal, 2020, pp. 885-893, doi: 10.1109/EDUCON45650.2020.9125364.

[3] Gallagher, S.E. & Savage, T. (2020). Challenge-based learning in higher education: an exploratory literature review. *Teaching in Higher Education*, DOI: 10.1080/13562517.2020.1863354

[4] Thomas, R.M. (2001). *International Encyclopedia of the Social & Behavioral Sciences*, 4197-4200

[5] Ibwe, K. S., Kalinga, E. A., Mvungi, N. H., Tenhunen, H., & Taajamaa, V. (2018). The impact of industry participation on challenge based learning. *International Journal of Engineering, Science and Innovative Technology*, 34 (1), 187–200.

[6] Nascimento, N., Santos, A., Sales, A., & Chanin, R. (2019). *An Investigation of Influencing Factors when Teaching on Active Learning Environments*. Proceedings of the XXXIII Brazilian Symposium on Software Engineering (SBES 2019). Association for Computing Machinery, New York, NY, USA, 517–522. DOI:https://doi.org/10.1145/3350768.3353819

[7] Author, xxxx

[8] Van den Akker, J. (2003). Curriculum perspectives: An introduction. In J. Van den Akker, W. Kuiper, & U. Hameyer (Eds.), *Curriculum landscapes and trends* (pp. 1–10). Dordrecht, The Netherlands: Kluwer.

[9] Malmqvist, J., Kohn Rådberg, K., and Lundqvist, U. (2015), *Comparative analysis of challenge-based learning experiences*. In CDIO (Ed.), Proceedings of the 11th International CDIO Conference. Chengdu, Sichuan, P.R. China: Chengdu University of Information Technology.

[10] Baloian, N., Hoeksema, K., Hoppe, U., & Milrad, M. (2006). Technologies and educational activities for supporting and implementing challenge-based learning. In D. Kumar & J. Turner (Eds.), *International Federation for Information Processing, Volume 210, Education for the 21" Century-Impact of ICT and Digital Resources* (pp. 7-16). Boston: Springer.

[11] Lammi, M., Denson, C., & Asunda, P. (2018). Search and Review of the Literature on Engineering Design Challenges in Secondary School Settings. *Journal of Pre-College Engineering Education Research*, 8(2). https://doi.org/10.7771/2157-9288.1172

[12] Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P–12 classrooms. *Journal of Engineering Education*, 97(3), 369–387.

[13] Larsson, J., and J. Holmberg. (2018). Learning While Creating Value for Sustainability Transitions: The Case of Challenge Lab at Chalmers University of Technology. *Journal of Cleaner Production*, 172, 4411-4420

[14] Kohn Rådberg, K., Lundqvist, U., Malmqvist, J. & Svensson, O. (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, DOI: 10.1080/03043797.2018.1441265

[15] Membrillo-Hernández, J., J. Ramírez-Cadena, M., Martínez-Acosta, M., Cruz-Gómez, E., Muñoz-Díaz, E., & Elizalde, H. (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

[16] Gero, A. (2014). Enhancing systems thinking skills of sophomore students: An introductory project in electrical engineering. *International Journal of Engineering Education*, 30(3), 738–745.

[17] Crawley, E. F. (2001). *The CDIO syllabus. A statement of goals for undergraduate engineering education. Massachusetts Institute of Technology: Department of Aeronautics and Astronautics*. Retrieved from http://www.cdio.org/files/CDIO_Syllabus_Report.pdf

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

[19] Bocconi, S., Kampylis, P., & Punie, Y. (2012). *Innovating teaching and learning practices: Key elements for developing creative classrooms in Europe*. eLearning Papers, 30, 1–13.

[20] Edson, A. J. (2017). Learner-controlled scaffolding linked to open-ended problems in a digital learning environment. *ZDM Mathematics Education*. doi:10.1007/s11858-017-0873-5.

[21] Pepin, B. & Kock, Z.-J. (2019). Towards a better understanding of engineering students' use and orchestration of resources: actual student study paths. In U.T. Jankvist, M. Van den Heuvel-Panhuizen & M. Veldhuis (Eds.), *Proceedings of the Eleventh Congress of the European Society for Research in Mathematics Education*. Utrecht: Freudenthal Group & Freudenthal Institute, Utrecht University and ERME.

[22] Hernández-de-Menéndez, M., Vallejo Guevara, A., Tudón Martínez, J.C., Hernández Alcántara, D., & Morales-Menendez, R. (2019). Active learning in engineering education. A review of fundamentals, best practices and experiences. *Int J Interact Des Manuf* **13,** 909–922 (2019). https://doi.org/10.1007/s12008-019-00557-8

[23] Kalinga, E. & Tenhunen, H. (2018). Active Learning through Smart Grid Model Site in Challenge Based Learning Course. *Systemics, cybernetics and informatics*, 16(3).

[24] Maya, M., Garcia, M. Britton, E., & Acuña, A. (2017). *Play Lab: Creating Social Value Through Competency and Challenge-Based Learning*. 19th International Conference on Engineering and Product Design Education, E and PDE 2017, Oslo, Norway.

[25] Nichols, M., Cator, K., & Torres, M. (2016). *Challenge Based Learner User Guide*. Redwood City, CA: Digital Promise.

[26] Magnell, M. & Högfeldt, A.K. (2015). *Guide to Challenge Driven Education*. Stockholm: KTH

[27] Piironen, A., Ikonen, A., Saurén, K., & Lankinen, P. (2009). *Challenge based learning in engineering education*. Paper presented at the 5th International CDIO Conference, Singapore.

[28] Binder, F. V., Nichols, M., Reinehr, S., & Malucelli, A. (2017). *Challenge based learning applied to mobile software development teaching*. Paper presented at the The 30th IEEE Conference on Software Engineering Education and Training, Savannah, GA.

[29] Balasubramanian, N., & Wilson, B. G. (2007). Learning by design: Teachers and students as co-creators of knowledge. *Educational Technology: Opportunities and Challenges, Oulu, Finland: University of Oulu*, 30:51.

[30] Botha, A. & Herselman, M. (2016). *Rural teachers as innovative co-creators: An intentional Teacher Professional Development strategy*. CONFIRM 2016 Proceedings. 23.

[31] Jensen, M. B., Utriainen, T. M., & Steinert, M. (2018). Mapping remote and multidisciplinary learning barriers: Lessons from challenge-based innovation at CERN. *European Journal of Engineering Education*, *43*(1), 40–54. https://doi.org/10.1080/03043797.2017.1278745

[32] Krohn, W. (2010). Interdisciplinary cases and disciplinary knowledge. In R. Frodeman, J. T. Klein, & C. Mitcham (Eds.), The Oxford handbook of interdisciplinarity (pp. 31–49). Oxford, UK: Oxford University Press.

[33] Huutoniemi, K., Klein, J. T., Bruun, H., & Hukkinen, J. (2010). Analyzing interdisciplinarity: Typology and indicators. *Research Policy*, 39, 79–88. https://doi.org/10.1016/j.respol.2009.09.011

[34] McNair, L. D., Newswander, C., Boden, D., & Borrego, M. (2011). Student and faculty interdisciplinary identities in self-managed teams. *Journal of Engineering Education*, 100(2), 374–396. https://doi.org/10.1002/j.2168-9830.2011.tb00018.x

[35] Johnson, L. and Adams, S., (2011). *Challenge Based Learning: The Report from the Implementation Project.* Austin, Texas: The New Media Consortium.

[36] Martin, S., Lopez-Martin, E., Moreno-Pulido, A., Meier, R., & Castro, M. (2019). A Comparative Analysis of Worldwide Trends in the Use of Information and Communications Technology in Engineering Education. *IEEE Access*, 7, pp. 113161-113170. doi: 10.1109/ACCESS.2019.2935019.

[37] Rashid, M. (2015). System level approach for computer engineering education. *International Journal of Engineering Education*, 31(1), 141–153.

[38] Lantada, A. D., Bayo, A. H., & Sevillano, J. D. J. M. (2014). Promotion of professional skills in engineering education: Strategies and challenges. *International Journal of Engineering Education*, 30(6), 1525–1538.

[39] Mielikäinen M. Towards blended learning: Stakeholders' perspectives on a project-based integrated curriculum in ICT engineering education. *Industry and Higher Education*. February 2021. doi:10.1177/0950422221994471