How to capture student learning in challenge-based learning – a proposal for a longitudinal study

eapril

European Association for Practitioner Research on Improving Learning

CONFERENCE PROCEEDINGS 2024

ISSUE 10 – MARCH 2025

ISSN 2406-4653

Helker, K., Reymen, I. M. M. J., Bruns, M., & Vermunt, J. D. (2025). How to capture student learning in challenge-based learning – A proposal for a longitudinal study. In *European Association for Practitioner Research on Improving Learning - Conference Proceedings 2024* (Vol. 10, pp. 103-114) https://eapril.org/assets/images/FINAL.pdf

HOW TO CAPTURE STUDENT LEARNING IN CHALLENGE-BASED LEARNING – A PROPOSAL FOR A LONGITUDINAL STUDY

Kerstin Helker*, **Isabelle Reymen****, **Miguel Bruns*****, **Jan D. Vermunt******

*Postdoctoral Researcher, innovation Space, Eindhoven University of Technology, Eindhoven, The Netherlands, k.helker@tue.nl, **Scientific Director, innovation Space, Eindhoven University of Technology, Eindhoven, The Netherlands, i.m.m.j.reymen@tue.nl, ***Professor, Industrial Design, Eindhoven University of Technology, Eindhoven, The Netherlands, mbruns@tue.nl, ****Professor emeritus, Eindhoven School of Education, Eindhoven University of Technology, Eindhoven, The Netherlands, j.d.h.m.vermunt@tue.nl.

ABSTRACT

Recent years have seen increasing calls for a more modern and flexible university education that prepares students for an increasingly complex and ambiguous world. As an educational concept responding to such calls, Challenge-Based Learning (CBL) has been implemented by an increasing number of higher education institutions. CBL puts students in the lead of their own learning, working on authentic and real-life challenges, collaborating with other learners and stakeholders to define learning and working goals. Research systematically exploring student learning processes in CBL and specifically student learning outcomes however remains scarce. In a pilot study, we therefore explored the learning gains CBL alumni reported to have taken away from a CBL learning experience. Participants reported many advantages of CBL and having acquired a broad number of personal and professional skills, but also named disadvantages of CBL learning processes. Therefore, we present a proposal for a longitudinal study of student learning in CBL in the second part of the paper. This longitudinal study should follow students on their path through higher education, capturing their learning process, perceptions of the CBL learning environment, and learning gains during each CBL course they encounter. This would allow us to get a better understanding of how CBL learning experiences affect student learning in other (both CBL and non-CBL) courses and foster the development of most beneficial conceptions of learning as well as processing and regulation strategies.

INTRODUCTION

Over the last years, Challenge-Based Learning (CBL) has gained popularity with higher education institutions looking to implement more authentic, real-life, and future-proof education. Since then, much research has emerged aiming to capture the different forms and definitions of CBL and student learning experiences in CBL. Research systematically exploring student learning processes in CBL and specifically student learning outcomes however remains scarce. This is a specifically pressing issue as one of the main points of evaluation of innovative educational concepts such as CBL is whether students truly acquire as much or more content knowledge as students in more traditional classrooms.

In this paper, we present the outcomes of a pilot study of learning outcomes of CBL alumni. Based on this, we make a suggestion for a larger longitudinal study of student learning processes and outcomes in CBL and present some methodological considerations.

THEORETICAL BACKGROUND

Recent years have seen increasing calls for more modern and flexible university education that prepares students for an increasingly complex and ambiguous world. This is specifically true for engineering education. Already in 2018, Graham explored "The global state of the art in engineering education" and identified a trend "to move towards socially-relevant and outward-facing engineering curricula" that "emphasise student choice, multidisciplinary learning and societal impact, coupled with a breadth of student experience outside the classroom, outside traditional engineering disciplines and across the world." (p. iii). This is not only crucial for students to be able to make sense of their learning and see the future usefulness of learning contents, but also to enable students to respond to future challenges that are not even known to them yet.

In a response to the above needs, Challenge-Based Learning (CBL) has been implemented in several educational contexts around the world, being most popular as an innovative educational concept for higher education (for a review, see Gallagher & Savage, 2020) and even more so in higher engineering education (for a review, see Doulougeri et al., 2024). Although its wide and various implementation has yielded many different forms and definitions of what CBL is, van den Beemt et al. (2020) define CBL in higher engineering education as

> "an interdisciplinary experience where learning takes place through identification, analysis, and collaborative design of a sustainable and responsive solution to a sociotechnical problem of which both the problem and outcomes are open. CBL at least involves (1) open ended problems from real world practice that require working in interdisciplinary teams, (2) entrepreneurial acting and design thinking, (3) combining disciplines, and (4) linking curricular and extracurricular activities.

> CBL both deepens disciplinary knowledge and stimulates 21st century skills such as self-awareness, self-leadership, teamwork, and an entrepreneurial mindset." (p. 62)

While CBL has strong conceptual links to other approaches of creative and interdisciplinary learning, it however allows students to dive into the full technical complexity of the respective challenge they are working on and the resulting social and technological problems (Malmqvist et al., 2015). Prior research on CBL has shown student learning gains regarding industry networking, improving technical skills, applications of skills in a real-world environment, training in multidisciplinary teamwork, improving problem solving skills, and achieving a deeper understanding of knowledge (see Gallagher & Savage, 2020 for a review).

Despite the obvious advantages of students working on authentic, real-life challenges, the question remains what learning processes students realize in CBL and how learning outcomes can be described. Therefore, Helker et al. (2024a) developed a framework of student learning in CBL, where student learning patterns and learning gains are assumed to be affected not only by students' personal factors (such as personal background, educational experience, age, gender, and also experience with CBL and interdisciplinary work) but also contextual factors. These contextual factors are conceptualised as multilevel (micro, meso-, exo- and macrolevel) and comprising distinct types of (physical, social, and formal) content.

LEARNING GAINS IN CHALLENGE-BASED LEARNING

Learning gains in higher education have been defined as "students' change in knowledge, skills, attitudes, and values that may occur during higher education across disciplines" (Vermunt et al., 2018, p. 272). This change is conceptualized to consist of a cognitive, metacognitive, affective, and socio-communicative component. Prior CBL research has analysed student and academic feedback and indeed found benefits for students in industry networking, improving technical skills, applications of skills in a real-world environment, training in multidisciplinary teamwork, improving problem solving skills, and achieving a deeper understanding of knowledge (see Gallagher & Savage 2020 for a review – referring to Cheung et al., 2011; Conde et al., 2017; Gama et al., 2019; Membrillo-Hernandez et al., 2019; Rådberg et al., 2020). In a recent review of the literature, Perna and colleagues (2023) found that CBL "enhances students' sense of meaning in their education (Bernard et al., 2016; Gallagher & Savage, 2020), promotes student reflective practice, self-regulation and metacognition (Bohm et al., 2020; Doulougeri et al., 2022; Tang & Chow, 2020) and is effective in increasing student engagement, motivation and participation, all elements that are considered of paramount importance by contemporary educational institutions." (p. 17)." Further learning gains in CBL compared to traditional lecture-based education regarding interdisciplinary thinking, self-directed learning, collaboration skills and engagement as well as disciplinary knowledge and skills have also been studied and findings suggest positive learning effects of CBL on students critical thinking, problem-solving skills, creativity, and communication (e.g., Ardiansyah & Asikin, 2020; Colombelli et al., 2022; Johnson et al., 2009; Martin et al., 2007) as well as content mastery (e.g., Bohori et al., 2022; Membrillo-Hernández et al., 2019).

PILOT STUDY – CBL ALUMNI LEARNING GAINS

The data in these studies on student learning outcomes in CBL have however often been collected during or right after students' CBL experience which does not allow for inferences on whether these learning outcomes and described effects of studying through the CBL approach are lasting. Therefore, Helker et al. (2024b) invited all students at a particular university of technology who had ever participated in a CBL course at their institution before to take part in an online survey exploring various aspects of their CBL learning experience, starting off with questions about the course they attended, what motivated them to take this course and what they felt were the advantages and disadvantages of CBL. To capture their personal learning gains, participants could indicate to what extent they saw added value of their CBL experience in their academic life, professional life and career, and their personal life. If participants saw at least some value, they were asked to further comment on how they had benefitted or were still benefitting from their CBL experience and what key learnings they had taken away.

20 CBL alumni participated in the study (8 female, 10 male, 2 not identifying; age: M = 24.8, SD = 7.09). By the time of responding, nine participants had finished university education, five were continuing at the same and another five at another university.

The survey results showed that students name a range of reasons why they had followed CBL courses. Among these, the courses' interdisciplinary set-up, the variety of interesting projects (e.g., *"I liked the diverse set of challenges and the fact that you worked with others in a group."* #5) and the perspective to be able and apply knowledge and skills to real-life problems (e.g., *"I liked the applied research aspect of it, as well as the possibility to work together with other people and improve my soft skills along the way."* (#7); "*It seemed more interesting than a regular Bachelor End Project as there was group work involved*" (#17)). Furthermore, several students mentioned that the course had been recommended to them.

The likelihood of students recommending CBL courses to other students ranged from 20 to 90% (M=69.07; "*I would highly recommend it, but not every student would fit this kind of work*." (#5); "*I learned more from my course than any other course at the university.*" (#8)) with students describing a large variety of advantages and disadvantages of CBL:

Advantages of CBL that were described were the interdisciplinary nature of the CBL courses, opportunities for applying their knowledge and skills to a real-life problem (e.g., "*I think it resembles the 'real world' more. So I think you learn a lot of skills that are really valuable for the future. I also think that projects can feel more relevant because they are based in a challenge.*" #11), collaboration with other students and having to deal with uncertainty were described as more interesting and motivating than regular courses: e.g., "*The freedom means that you have to guide your own work, which teaches you to think, work, design and engineer without a course prescribing every step. This is more realistic compared to real engineering jobs*." (#5), "*You learn to work on a real world problem, instead of pre-defined exercises with pre-defined answers. You become more used to uncertainty*." (#18). The freedom in their learning students experienced in CBL courses were at the same time also described as a disadvantage of CBL – specifically the perceived lack of structure and supervision: e.g., "*The lack of structure can be a bit of a pitfall for students that haven't learned how to make their own structure yet (CBL for first year students is a horrendously terrible idea)*." (#7). Students furthermore mentioned the difficulty for students and teachers in CBL to capture student learning (e.g., "*There's a risk of unclear assessment because the learning is so open. This can cause confusion and unclear/misaligned expectations. In your job, you've done well when the client is happy, but that's of course not enough for Challenge-Based Learning*." (#12)) and that CBL might even "*not provide as much in-depth content knowledge as regular courses or projects.*" (#3).

Participants however described key learning outcomes such as collaboration skills, ability to deal with uncertainty, problem-solving skills, project management, communication and networking skills, and many more. One person indicated they had not taken away any learnings. When asked to indicate whether CBL had helped them develop each of a list of 13 personal and professional competences, positive responses were highest for Social Awareness, Dealing with Uncertainty, Communicating, Self-directed Learning and Pro-activity.

These outcomes support prior work emphasizing the variety of student learning outcomes of CBL, but also fuel on-going discussion in CBL research and practice on what and how much guidance is needed and how learning outcomes can best be assessed.

A CALL FOR FUTURE RESEARCH

The above findings call for a more overarching study of CBL in higher education. Up to today, however, the above framework of CBL (Helker et al., 2024a) and the numerous assumptions on the advantages of CBL, including student learning gains, have not been put to the test in large-scale empirical research with students in Challenge-Based Learning environments. Such a study, however, becomes more urgent the more higher education institutions re-design their courses and programs to CBL teaching and learning settings.

Based on the above, we argue for a study that explores the following research questions:

1) How is Challenge-Based Learning (CBL) as an educational concept implemented in different Bachelor programs and courses?
2) What are students' learning patterns in CBL?
3) What are students' learning outcomes in CBL?
4) How do student motivation and educational background influence learning patterns and outcomes in CBL courses?

STUDY PROPOSAL

Context and setting

Following Graham's (2018) statement that innovations in engineering education are likely to be successful if they can be integrated at scale to large cohorts and under constrained budget (p. 45), Eindhoven University of Technology (TU/e) decided to place CBL at the core of their educational vision 2030, by establishing a CBL curricular line across the Bachelor College. This means that every Bachelor programme offers a certain number of courses in a CBL format with an increasing interdisciplinarity, complexity and open-endedness, so that students at the end of the second year are proficient in CBL working and learning formats, and that they can successfully participate in a multidisciplinary CBL course. The agreed essential CBL characteristics include that (a) challenges are real-life and authentic, (b) learning activities create a rigorous treatment of fundamental engineering knowledge and skills, and (c) challenges stimulate the combination of deep understanding and broader view (Van den Beemt et al., 2023).

Despite this standardisation, the specific set-up of each of the courses of the CBL curriculum line and how they are being implemented in the programme varies per Bachelor programme. Some of the departments have over the last years already gathered more experience with CBL re-design and implementation than others, who are doing their first steps now. TU/e has developed some structures to support this process. Nevertheless, up until now, no studies have been conducted that have compared student learning in differently set-up CBL courses on such a large scale.

Research Methodology

In order to answer the above research questions, we suggest recruiting students from all CBL courses of all Bachelor programmes, i.e. all courses that are part of the CBL curriculum line. In order to capture the general considerations of the specific programmes for their students' learning processes and outcomes, we suggest conducting interviews with programme directors or program managers. In these interviews we also hope to understand the general philosophy of the programme and why certain courses were chosen to be re-designed to CBL.

For each of the specific CBL courses, we are planning to conduct interviews with teachers, starting off with a number of practical questions on the course (How many students are enrolled, educational background of students, student-to-teacher-ratio, (dis)advantages of CBL in general and in this specific set-up). The first part will be focusing on the implementation of the course, guided by the CBL compass (Van den Beemt et al., 2023). Teachers will be asked to rate on a 4-point scale (from 1="not implemented" to 4="fully implemented"), several items on the real-life and open nature of the challenges in their course, their collaboration with stakeholders, education of T-shaped engineers, self-directed learning, collaborative learning, interdisciplinarity, learning technology, and assessment.

At the core of the study, we are planning several occasions at which we collect data from students: (1) at the beginning of their studies, during the first week of university, (2) at the beginning of each CBL course, (3) in the middle of each CBL course, and (4) every six months. The contents of each of these data collection points will in the following be described in more detail:

(1) At the beginning of their studies, students will be asked to respond to a number of questions on their educational background (e.g., prior degrees, secondary education), professional background (e.g., prior employment), and experience with interdisciplinary, challenge-based, and/or collaborative teamwork. Furthermore, we include a scale to capture student grit (Duckworth & Quinn, 2009, 8 items, e.g., "New ideas and projects sometimes distract me from previous ones." scale: 1= "strongly disagree" – 6= "strongly agree") and students' overall study motivation (Vallerand et al., 1992, 28, items, e.g., Why are you taking up university studies? "…because I experience pleasure and satisfaction while learning new things." scale: 1= "strongly disagree" – 6= "strongly agree") including the subscales intrinsic motivation – to know, intrinsic motivation – experience stimulation, intrinsic motivation – accomplishment, extrinsic motivation – introjection, extrinsic motivation – external, and amotivation.

(2) At the beginning of each CBL course, we will capture student course motivation (Kosovich et al. 2015; 9 items, e.g., "I believe that I can be successful in this course." scale: 1= "strongly disagree" - 6= "strongly agree").

(3) During each course, students will respond to survey questions aiming to understand their learning patterns and perception of the learning environment. Student learning patterns will be captured with an instrument developed by Vermunt, Ilie, and Vignoles (2018), with subscales capturing students' relating and structuring (7 items, e.g., "I try to relate new subject matter to knowledge I already have about the topic."), critical processing (4 items, e.g.," I draw my own conclusions on the basis of data that are presented."), concrete processing (5 items, e.g., "I use what I learn from a course in

my activities outside my studies.”), self-regulation (6 items, e.g., “I also pursue learning goals that have not been set by the lecturers but by myself.”), lack of regulation (5 items, e.g., “The study directions which are given are not very clear to me.”) as well as self-management (7 items, e.g., “I’m very good at making time to study.”). Social engagement (6 items, e.g., “I try to help others who are struggling.”) and emotional engagement (5 items, e.g., “I look forward to this course.”). These subscales will be measured with the instruments developed by Fredricks, Wang, et al. (2016) and Wang, Fredricks, Ye, Hofkens, & Linn (2016).

Students’ perceptions of the learning environment will be explored using Könings and colleagues’ (2014) instrument, with subscales to capture students’ perception of fascinating contents (8 items, e.g., “Most of what I learn is interesting.”), integration (4 items, e.g., “Most sessions of this course are focused on practice.”), student autonomy (9 items, e.g., “Students are free to choose the way in which they learn the content.”), differentiation (4 items, e.g., “All students in the course do the same work at the same time.”) and clarity of goals (2 items, e.g., “Students know what to expect at tests and exams.”). All items are responded to on a 5-point Likert scale.

(4) In order to capture student learning outcomes, we have decided not to collect data after each of the CBL courses but every six months. This way, student reports on learning outcomes will not be tainted by their experiences of the learning process (post-group euphoria, e.g., Marsh et al. 1986). In these surveys, we will present the overall learning goals of the specific Bachelor programme and ask students to self-assess their competence level for each of these learning goals. Furthermore, we will ask students in an open-ended question which activities they attribute the development of the respective competence to, and expect students to either name curricular or extracurricular activities at university or even activities independent of their studies. Furthermore, students will be presented 14 personal and professional competences (e.g., communicating, collaborating, planning & organizing, dealing with scientific information, taking responsibility, dealing with uncertainty) and will be asked on a four point scale, to which extent they would like this respective competence to describe them in the future and to what extent they feel they have already developed this competence.

Methodological Considerations

There are some limitations of the study plan that should be addressed in all clarity. First of all, in this study setup, no data will be collected in non-CBL courses. This decision was made in order not to overload students with surveys, also considering that the data would not provide more beneficial information. Of course, studies researching the effectiveness of CBL would benefit from the comparison of a CBL experiment with a control group of students that study the same learning contents in a traditional learning context. This, however, is rather impossible given that in CBL, teachers cannot plan for the contents students study as the students often define the problem and learning goals as part of their autonomous working process on the challenge.

Another limitation of this study is, that students' learning outcomes cannot be clearly linked to the individual CBL courses as data on student learning gains will be collected every six months irrespective of whether and how much students have studied in CBL environments in the proceeding time period. Until there is an opportunity to conduct similar six-monthly data collection on student learning gains at a university with a more traditional educational concept aiming at the same learning contents, the current study will only provide insights on student learning outcome development over time. It may well be that the CBL courses have focused on knowledge application whereas the more traditionally set-up courses such as lectures served knowledge acquisition. Only students' self-reported data on which study activities they attribute the learning gain to, will serve as an indicator for now. Nevertheless, we will refrain from using student exam results as indicators of student learning. Not all courses that will be researched in this study include exams in their assessment plans and if they do, exams can only capture student learning gains anticipated by the teacher when designing the course.

CONCLUSIONS

While there is an increasing amount of research trying to capture student learning processes and outcomes in Challenge-Based Learning, it has mostly focused on students' application of previously acquired content knowledge and development of personal and professional skills. Many teachers argue that learning outcomes in CBL may only be fully visible a while after the CBL experience when students move on to other educational or professional contexts. Own prior research has yielded some insights into the learning outcomes of CBL alumni, but we argue for a thorough longitudinal study following students on their path through higher education. This would allow us to get a better understanding of how CBL learning experiences affect student learning in other (non-)CBL courses and foster the development of most beneficial conceptions of learning as well as processing and regulation strategies.

ACKNOWLEDGEMENTS

The authors would like to thank Michael Bots and Gerards van de Watering for their invaluable feedback on the design of the study.

REFERENCES

Ardiansyah, A. S., & Asikin, M. (2020). Challenging students to improve their mathematical creativity in solving multiple solution task on challenge based learning class. *Journal of Physics: Conference Series*, 1567(2), 22088.

Bernard, J., Edström, K. & Kolmos, A. (2016). Learning Through Design–Implement Experiences: A Literature Review. In *Proceedings of the 12th International CDIO Conference*, June 12–16. Turku: Turku University of Applied Sciences.

Bohm, N. L., Klaassen, R. G., den Brok, P. J., & van Bueren, E. (2020). Choosing challenges in challenge-based courses. In *Engaging engineering education: SEFI 48th annual conference proceedings*, pp. 98-109.

Bohori, M., Liliawati, W., Suwarma, I. R., & Ringo, S. S. (2022). The Rasch Analysis of Students' Characteristics in Physics Concept Understanding Improvement through Challenge-Based Learning. *Jurnal Penelitian & Pengembangan Pendidikan Fisika, 8*(2), 207-216.

Colombelli, A., Loccisano, S., Panelli, A., Pennisi, O. A. M., & Serraino, F. (2022). Entrepreneurship education: the effects of challenge-based learning on the entrepreneurial mindset of university students. *Administrative Sciences, 12*(1), 10.

Cheung, R. S., Cohen, J. P., Lo, H. Z., & Elia, F. (2011). *Challenge Based Learning in Cybersecurity Education.* Proceedings of the International Conference on Security and Management (SAM), Las Vegas, NV, USA.

Conde, M., García-Peñalvo, F. J., Fidalgo-Blanco, Á. & Sein-Echaluce, M. L. (2017). *Can we Apply Learning Analytics Tools in Challenge Based Learning Contexts?* Paper presented at the International Conference on Learning and Collaboration Technologies, Vancouver, Cananda.

Doulougeri, K., van den Beemt, A., Vermunt, J. D., Bots, M., & Bombaerts, G. (2022). Challenge-Based Learning in Engineering Education: Toward Mapping the Landscape and Guiding Educational Practice. In *The Emerald Handbook of Challenge Based Learning*, pp. 35-68. Emerald Publishing Limited.

Doulougeri, K., Vermunt, J. D., Bombaerts, G., & Bots, M. (2024). Challenge-based learning implementation in engineering education: a systematic literature review. *Journal of Engineering Education, 113*(4), 1076-1106. Retrieved from https://doi.org/10.1002/jee.20588

Duckworth, A. L., & Quinn, P. D. (2009). Development and validation of the short grit scale (GRIT–S). *Journal of Personality Assessment, 91*(2), 166–174.

Fredricks, J. A., Wang, M.-T., Schall Linn, J., Hofkens, T. L., Sung, H. C., Parr, A. K., & Allerton, J. J. (2016). Using qualitative methods to develop a survey measure of math and science engagement. *Learning and Instruction, 43*(6), 5-15.

Gallagher, S. E., & Savage, T. (2020). Challenge-based learning in higher education: An exploratory literature review. *Teaching in Higher Education, 28,* 1135–1157.

Gama, K., Alencar, B., Calegario, F., Neves, A., & Alessio, P. (2019). *A Hackathon Methodology for Undergraduate Course Projects.* Paper presented at the 48th Frontiers in Education Conference, FIE 2018, San Jose, CA, USA.

Graham, R. (2018). The global state-of-the-art in engineering education. Outcomes of Phase 1 benchmarking study. Retrieved from https://rhgraham.org/resources/Phase-1-engineering-education-benchmarking-study-2017.pdf

Helker, K., Bruns, M., Reymen, I. M., & Vermunt, J. D. (2024a). A framework for capturing student learning in challenge-based learning. *Active Learning in Higher Education*, online first publication, 14697874241230459. doi:10.1177/14697874241230459

Helker, K., Reymen, I. M., & Bruns, M. (2024b). Challenge-Based Learning – the way to authentic and sustainable learning? Paper presented at the European Association for Practitioner Research on Improving Learning Conference, Hasselt, Belgium.

Johnson, L. F., Smith, R. S., Smythe, J. T., & Varon, R. K. (2009). *Challenge-based learning: An approach for our time*. The New Media Consortium.

Könings, K. D., Brand-Gruwel, S., Merrienboer, J. J. G. v., & Broers, N. J. (2008). Does a New Learning Environment Come Up to Students' Expectations? A Longitudinal Study. *Journal of Educational Psychology, 100*(3), 535-548. doi:10.1037/0022-0663.100.3.535

Kosovich, J. J., Hulleman, C. S., Barron, K. E., & Getty, S. (2015). A Practical Measure of Student Motivation: Establishing Validity Evidence for the Expectancy-Value-cost Scale in Middle School. *Journal of Early Adolescence, 35*(5-6), 790-816. doi:10.1177/0272431614556890

Malmqvist, J., Kohn Rådberg, K., & Lundqvist, U. (2015). Comparative analysis of challenge-based learning experiences. In *Proceedings of the 11th International CDIO Conference*, 8-11 June 2015. Chengdu University of Information Technology.

Marsh, H. W., Richards, G., & Barnes, J. (1986). Multidimensional self-concepts: A long-term follow-up of the effect of participation in an outward bound program. *Personality and Social Psychology Bulletin, 12*(4), 475–492.

Martin, T., Rivale, S. D., & Diller, K. R. (2007). Comparison of student learning in challenge-based and traditional instruction in biomedical engineering. *Annals of biomedical engineering, 35*, 1312-1323.

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, 13*(3), 1103-1113.

Perna, S., Recke, M. P., & Nichols, M. H. (2023). *Challenge Based Learning- A Comprehensive Survey of the Literature*. Retrieved from https://www.challengeinstitute.org/CBL_Literature_Survey.pdf

Rådberg, K. K., Lundqvist, U., Malmqvist, J., & Hagvall 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

Tang, A. C., & Chow, M. C. (2020). To evaluate the effect of challenge-based learning on the approaches to learning of Chinese nursing students: A quasi-experimental study. *Nurse Education Today, 85*, 104293.

Vallerand, R. J., Pelletier, L. G., Blais, M. R., Briere, N. M., Senecal, C., & Vallieres, E. F. (1992). The Academic Motivation Scale: A Measure of Intrinsic, Extrinsic, and Amotivation in Education. *Educational and Psychological Measurement, 52*(4), 1003-1017. doi:10.1177/0013164492052004025

Van den Beemt, A., MacLeod, M., & Van der Veen, J. (2020). *Interdisciplinarity in tomorrow's engineering education.* Paper presented at the 48th SEFI Annual Conference on Engineering Education, SEFI 2020.

Van den Beemt, A., van de Watering, G., & Bots, M. (2023). Conceptualising variety in challenge-based learning in higher education: the CBL-compass. *European Journal of Engineering Education, 48*(1), 24-41. doi:10.1080/03043797.2022.2078181

Vermunt, J. D., Illie, S., & Vignoles, A. (2018). Building the foundations for measuring learning gain in higher education: a conceptual framework and measurement instrument. *Higher Education Pedagogies, 3*(1), 266-301. doi:10.1080/23752696.2018.1484672

Wang, M.-T., Fredricks, J. A., Ye, F., Hofkens, T. L., & Schall Linn, J. (2016). The Math and Science Engagement Scales: Scale development, validation, and psychometric properties. *Learning and Instruction, 43*(6), 16-26.