Embedding industry 4.0 in operations management education using a Challenge-based Learning approach.

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Abstract

Challenge-based learning (CBL) is a cutting-edge educational approach that integrates traditional learning modules (theory and practice) and real-life challenges that require solutions. Learning modules are specifically designed to provide the necessary theoretical and practical knowledge to solve the challenges. In this paper, we propose an approach for the use of CBL in Operations Management education, with a focus on industry 4.0 technologies, and present findings from its implementation based on students' first-hand experiences. Results suggest that the proposed CBL approach increased students' understanding of OM in real-life settings, and was conducive to students' development of 21st century skills.

Keywords: Industry 4.0 technology, curriculum design, educational innovation.

Introduction

The urgency to introduce new skills in our workforce is not new; what seems to have changed is what we need to learn if we aspire to be better professionals in the future. This has been attested by The World Development report (2019) on *The Changing Nature of Work*. Through its pages, an argument is built concerning the management of our operations in the future, and the need for professionals capable of making decisions in volatile and unbounded circumstances, where data available might be too limited or too excessive. Digital approaches, through the use of robots and Artificial Intelligence might be a palliative, but not a substitute for supporting such highly complex decision-making. This suggests that one imminent global challenge concerns the preparation of future professionals for a different labor market. However, planning how to prepare people for such challenge is not a simple task.

Education planning is built around exercises of 'curriculum development', which involves processes of conception, creation, implementation, execution, monitoring and control, and reflection. These are usually nested in different steps: (1) evidence-gathering, (2) preparation, (3) development, (4) implementation, and (5) monitoring and evaluation (UNESCO, 2017). These steps are not necessarily linear, as previous steps might need to be revisited. What is always the case is that the initial conception and the final outcome are separated in time, which suggests the metaphor of a 'delayed' process. For instance, preparing future professionals for a different labor market may be approached by focusing on children entering primary school. This might not be the preferred strategy, as it seems impossible to foresee future working conditions and labor requirements in 20 years' time.

Another possibility is to reduce the distance between input and output by introducing working abilities later on. For example, we may develop such abilities at university level; where teenagers and mature students are looking for more advanced (re-)training. This delay suggests that the challenge of how to support people to become better professionals in a digital complex working environment is, at least, two-folded. On one side, there is the need to investigate what are the abilities required in the future; and on the other, to identify when is the best moment to acquire such abilities.

Concerning the first question, 'what abilities to develop?', the four pillars of learning are recognized as "to know, to do, to be and to live together" (UNESCO, 2015); but in a mobile and digital world, the increased mobility of workers and learners is pushing towards open and flexible lifelong learning systems. As a consequence, current learning approaches are moving from traditional communications systems, where the quality of information transmission was the main performance criteria, and future learning approaches will be seen as effective in a digitalized world, if they provide "a combination of technological know-how, problem-solving, and critical thinking, as well as soft skills such as perseverance, collaboration, and empathy" (World Bank, 2019). In reference to the second question, this paper focuses on how provide this expected combination of know-how and skills to students that will be involved in the future in the management of operations, within a mobile and digital world.

This paper reports lessons learned concerning the Challenge-based Learning (CBL) approach. The paper provides a real example on how to implement the answers to both questions; which know-how and skills are required for managing of operations in the future, and how students may embed such knowledge. Accordingly, the structure of this paper begins with a description on what Challenge-Based Learning (CBL) stands for. As an outcome of this review, an approach for the implementation of CBL in Operations Management education is presented. Subsequently, findings from the implementation of this approach are presented and discussed. Finally, some conclusions on the lessons learned are provided.

Background

CBL is a multidisciplinary teaching and learning approach that aims to increase students understanding of technology used in their daily lives to solve real-world problems (Apple, 2010). This concept is part of a larger collaborative project known as Apple Classrooms of Tomorrow – Today (ACOT2), an 1985 initiative involving public schools, universities, research agencies, and Apple Computer, Inc. to introduce technology as a tool for learning, thinking, collaborating, and communicating, inside classrooms (Ringstaff and Yocam, 1996). CBL is constituted by interlinked steps that guide the design and implementation of learning spaces, which are not confined by classroom walls. The impact of these learning spaces can be found beyond traditional boundaries, as CBL also considers activities to share findings with the wider community; activities that make use of physical and digital means (Dutra Moresi et al., 2017).

CBL integrates aspects of other educational practices, such as problem-based learning (PBL), project-oriented learning (POL), and contextual teaching and learning (Johnson et al., 2009). Common aspects among these approaches are critical thinking, problem solving, collaborative learning, autonomy and others (Binder et al., 2017). The main difference between CBL and other approaches, lies in the use of real-life situations and the need for real, concrete solutions. Unlike POL or PBL, which often use predefined controlled situations or fictitious problem situations, CBL confronts students with an open, relevant problem for which there is no pre-made (universal) solution (Membrillo-Hernández et al., 2018), which tends to increase uncertainty and the need for self-direction.

Since its conception, CBL has been widely and successfully implemented across different levels of education, from elementary school (ages 8-11) to university (Johnson and Adams, 2011). The approach has been used to teach a variety of topics, such as nursing (Yang et al., 2018; Tang and Chow, 2020), aerospace engineering (López-Fernández et al., 2020), mechanical and mechatronics engineering (Lara-Prieto et al., 2019), sustainable development engineering (Membrillo-Hernández et al., 2018) and software development (Binder et al., 2017). These studies have documented multiple benefits, which include the improvement of key skill areas, such as creativity, problem solving, collaboration critical, communication, adaptability, innovation and others. In addition, existing evidence suggests that CBL also improves engagement with lessons and knowledge acquisition.

The flexibility of CBL allows its integration with other frameworks or techniques. Evidence of such successful integration has been reported (Binder et al., 2017). Thus, the present study proposes a CBL approach that integrates creative problem-solving techniques and reflective practice. Furthermore, the CBL approach integrates OM theory by including five performance objectives as criteria for evaluation and validation of solutions. This integrative approach aims to facilitate the adoption of CBL in OM education.

Experimental design

The general purpose of this research was to develop, implement and document a CBL approach to support students in the discovery of the potential role that industry 4.0 technologies can play in the improvement of operations management (OM), through the practical application of OM knowledge in a real-life situation, and the development of 21st century skills. In particular, we are interested to learn more about how students' experience a CBL approach within an OM module. The CBL approach was implemented in two terms from September 2019 to May 2020 at Lincoln International Business School, within the Operations Management module. The module consisted of 36 hrs. class contact (24 hrs. of lectures and 12 hrs. of seminars), 48 hrs. of CBL group work and 66 hrs. of self-study. This is a core module for second-year students enrolled in most undergraduate programs. The first term comprised 92 students and the second term comprised 205 students. During a period of 12 weeks, students worked in teams of between 5-8 students to solve the challenges. Each team was allocated a challenge to work on during the duration of the module. The real-life challenges were provided by regional businesses and were deemed to be feasible and relevant to the OM discipline by the academic team. The challenges are related to different operations within the businesses, but they all have in common that solutions can be based on the application of industry 4.0 technologies. Students were given briefings that explained their allocated challenges and contact information of the business providing the challenge. They also had a face-to-face meeting with representatives of the business partners in week 4.

The different elements of our CBL approach are depicted in figure 1. The CBL process consisted of four main steps: 'challenge structuring', 'brainstorming solutions', 'evaluating and selecting a final solution' and 'challenge reflection'. To carry out the three initial steps, students were supported with a lecture related to creative problem-solving techniques (Proctor, 2019) which is suitable when a given goal (i.e. challenge) exists but there is uncertainty regarding how to proceed. Because the focus of this CBL approach was industry 4.0 technologies, a lecture on industry 4.0 and its impact on OM was delivered and relevant resources (i.e. journal articles) were provided through the Blackboard site. Students were asked to frame their proposed solutions within the five operations 'performance objectives' proposed by Slack and Brandon-Jones (2019), namely quality, speed, cost, flexibility and dependability. To improve the relevance and significance of their proposed solutions, they

were asked to justify how their solutions supported the improvement of at least one performance objective. Once a solution was identified and validated, students carried out a reflection guided by Gibb's (1988) reflective cycle.

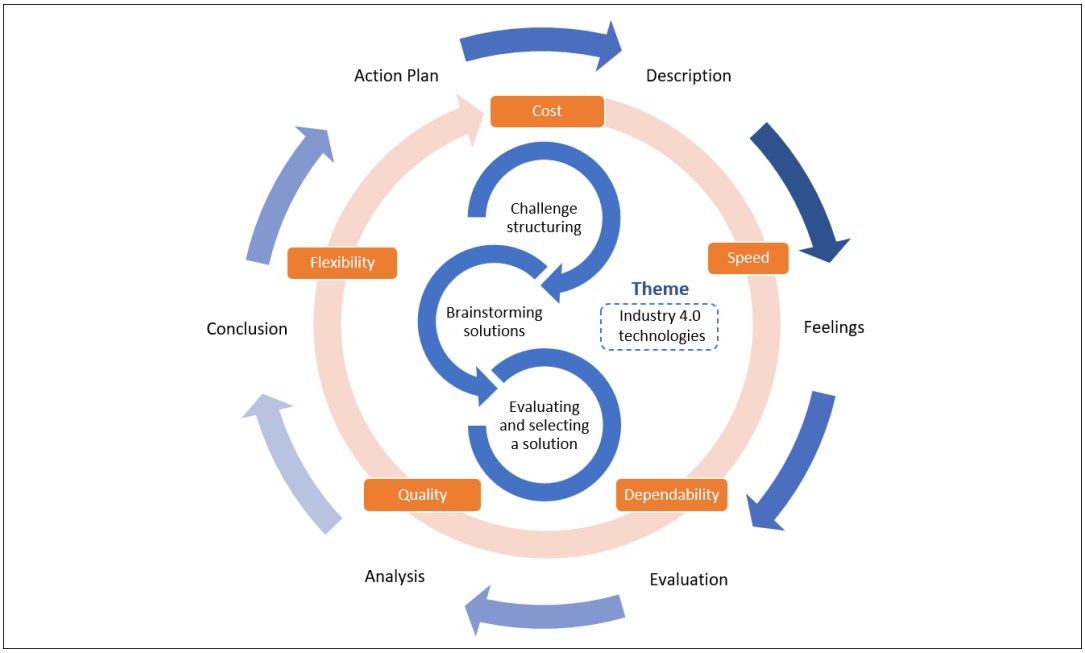

Figure 1 – Proposed approach for embedding CBL in Operations Management.

Students worked on the four different steps of the CBL process during most of the seminars that took place before week 10. They all provided an informal (verbal) progress report to tutors each week and had the opportunity to receive formative feedback along the way. Summative assessment was provided in week 10, when students presented their solutions to the public, academic staff and the business partners in poster showcases.

Data collection procedure

Document analysis was adopted as a research method in this study. It is a form of qualitative research that involves the selection, review, evaluation and synthesis of documents to gain understanding and empirical knowledge, typically by organizing selected data into themes or categories (Bowen, 2009). This method was chosen because of several advantages such as efficiency in terms of time (Bowen, 2009), availability of data and cost-effectiveness (Hodder, 2000), and the opportunity to gain access to the views of the whole population. Students reflections were the primary source of qualitative data. Reflections were included in the posters that all teams presented and submitted via Blackboard in week 10. Students were asked to adopt Gibb's (1988) reflective cycle model comprised of six steps: description, feelings, evaluation, analysis, conclusion and action plan. Each of these steps was guided by a question that students reflected on:

1. Description: What happened during the challenge?
2. Feelings: What were you thinking and feeling?
3. Evaluation: What was good and bad about the experience?
4. Analysis: Why do you think things went badly or well?
5. Conclusion: What could you have done differently? Or what did you learn about your strengths and weaknesses?
6. Action plan: What do you need to do to be better prepared for future challenges?

All reflections were extracted from posters submitted via Blackboard, anonymized and analyzed in search for emerging patterns.

Data analysis

The data analysis process was based on a six-phase thematic analysis approach (Braun and Clarke, 2006) aided using NVivo software. Thematic analysis can be valuable for highlighting the similarities and discrepancies among the views of different research participants (Nowell et al., 2017), and is particularly suited for document analysis (Bowen, 2009). The analysis involved an iterative process of coding, categorization of codes into overarching themes and naming of final codes and themes. As suggested by Guest et al. (2012), we used several techniques for the identification of themes, such as 'repetition' or looking for concepts that reoccur through the documents, 'linguistic connectors' or searching for phases that denote causal relations, and 'silence/missing data' or the absence of an emerging theme that was expected.

Research quality and rigor

When carrying out document analysis, researchers should consider and evaluate the quality and relevance of documents (Bowen, 2009; Hodder, 2000). The evidence used in this study is relevant as it facilitated the drawing of some initial conclusions regarding how students experienced a CBL approach within an OM module. It is assumed that the evidence is authentic and credible as the documents were provided directly to academic tutors by students, and were written as a result of a first-hand experience. The researchers also acknowledge that the documents (posters that contain the reflections) were solicited and not anonymous, which could have an impact in terms of reflexivity. Document analysis is usually 'unobtrusive' and 'non-reactive (Bowen, 2009). However, in this case, because the posters were subject to marking, some bias might have been introduced. In particular, there is a possibility that students might have provided reflections that highlighted the positive aspects and minimized the negative aspects of the experience. The researchers estimate that this possibility is slim, and could have been mitigated by the use of Gibbs' reflective framework which asks students to reflect on the negative aspects of an experience.

In order to address dependability, two researchers carried out all the phases of the thematic analysis separately (Lincoln and Guba, 1985). Then, final codes and themes were agreed between the researchers. Internal validity was addressed by comparing emerging findings with existing literature. Adopting this strategy can result in increased internal validity and generalizability (Eisenhardt, 1989). Lastly, the researchers aimed at providing a thick description of the experimental design to facilitate transferability of findings (Lincoln and Guba, 1985; Nowell et al, 2017).

Results and discussion

The results identified a range of themes and codes about how students experienced the CBL approach, as shown in Table 1. Overall, some similarity exists among the experiences reported by different teams. We identified four main themes that relate to 'the challenge', 'teamwork', 'feelings' and 'challenge-based learning'. The first theme encompasses codes that represent particular aspects of our proposed CBL approach but do not necessarily form part of every CBL intervention. For instance, our approach revolves around the use of digital technologies (as part of Industry 4.0) to solve challenges but CBL can be used under any thematic.

Table 1. Thematic analysis of students' experience with CBL in OM education

Themes	*Codes*	*Illustrative quotes*
1. The challenge	Industry 4.0	"It gave us the chance to look into industry 4.0 and what possibly opportunities it can bring to us as future graduates"

	Meeting with company	"As the challenge continued, we gained more clarity on the task as a result of performing extra research on the company and meeting the owner…"
	Poster	"Been difficult to create this poster to include all our findings and solution proposal"
	Techniques	"We have learned new models that have helped us to evaluate the best solution. Ideas that seem good aren't always as good after evaluation"
	Theory and materials	"For future reference, it should be further attempted to analyse topics from lectures by partaking in more further reading, to better equip ourselves with greater understanding of operational topics"
2. Teamwork	Communication	"We were able to come together to discuss ideas and tackle opposing opinions. The task required a lot of discussion before any meaningful progress was made"
	Contract	"Implementing the contract is something we would change as it was not present enough"
	Meetings	"We should have made more of an effort to meet every week to make more progress throughout"
	Planning	"For future challenges, a detailed plan as well as appropriate time spent on each section should be planned before getting our hands on the challenge"
	Task delegation	"If done again, start sooner and delegate roles with greater efficiency"
	Team building	"We could choose our own groups at the start so that we are confident in our team's ability to work efficiently as a unit"
3. Feelings	Confusion	"To begin with we felt confused and uncertain in relation to the challenge structuring as well as working with a real-life company as we had not done this before"
	Apprehension	"There were feelings of apprehension, because the nature of the challenge tested our knowledge for which we had no prior experience"
	Overwhelming	"At the beginning we felt very overwhelmed and felt incompetent to be able to devise a solution... due to us not having prior knowledge in this subject area"
	Confidence	"...the more research we did the more confident we felt about the challenge"
	Motivation	"Although our motivation was present at the beginning it definitely got stronger as a group as we progressed"
	Relief	"After completion we felt a sense of relief and felt that we did learn something and worked well as a group"
	Sense of achievement	"There was a sense of achievement when all the work was complete"
4. Challenge-based learning	The approach	"Took a while to adjust with it being so different from other modules"
	Problem solving	"...we feel like this has greatly improved our problem solving and teamworking skills"
	Innovation	"We also learned more about working collaboratively in innovation"
	Real life	"The experience was helpful as it put us in a real-world situation and made us think outside the box for creative and realistic solutions to the challenges put in front of us"

	Research	"We think that most of this project went smoothly due to our detailed research and understanding of the challenge"
	Solutions	"...we felt it was very important to research all the solutions extensively in order to undertake an accurate evaluation. We felt this was key to completing the challenge effectively and successfully"
	Tutor	"Seek help and support from the seminar tutor at the beginning when we feel we are struggling"

Students found the theme of the CBL approach useful as it increased their knowledge of Industry 4.0 and how it can benefit businesses. Other studies have reported favorable results regarding students' views on the level of knowledge acquisition in different areas of study such as Aerospace Engineering (López-Fernández et al., 2020), and Sustainable Development Engineering and Mechanical and Mechatronics Engineering (Membrillo-Hernández et al., 2018). Students found the 'Meeting with the company' to be beneficial to gain a better understanding of the task at hand. On the other hand, they felt that the form of assessment (i.e. poster) was restrictive as they found it difficult to include all their findings in the template provided. Overall, they found the use of problem-solving techniques to be beneficial to gain a better sense of the scenario at hand and develop a more critical approach to the evaluation of solutions. This finding is in line with current literature which acknowledges the ability of CBL in developing problem-solving skills in students (Gabriel, 2014; Johnson and Adams, 2011; Membrillo-Hernández et al., 2018). Another common theme was related to theory and materials. In this regard, it was often mentioned that if faced with a similar experience in future, they would do additional reading regarding OM theory but also around the topic of their allocated challenge.

Codes related to soft skills showed a lot of repetition. The most common codes within the theme 'Teamwork' were 'Meetings', 'Planning', 'Communication' and 'Task delegation'. Most shortcomings regarding team performance were attributed to these four elements of teamwork. In particular, students suggested that they should have been more organized in the early stages of group work which in turn would have made the whole process more efficient, and would have ensured that workload was split more evenly. In terms of 'Meetings' and 'Communication', some students suggested that they found it difficult to meet due to busy schedules. On the other hand, students who met regularly (i.e. each week) found it beneficial in terms of organization, communication and meeting deadlines. Previous literature has already documented issues related to teamwork in a CBL atmosphere. Membrillo-Hernández et al. (2018) suggested that the level of uncertainty involved in CBL highlights the importance of teamwork, critical thinking, planning ahead and resilience. Furthermore, a study by López-Fernández et al., (2020) found that students' relationships with their colleagues were not as good after a CBL intervention. This is to be expected when a learning approach involves teamwork but also highlights the importance of supporting students in the development of their soft skills.

Students' 'Feelings' were extensively reported. There were some students who reported 'positive feelings' from the start of the module, such us excitement, motivation, interest, optimism and confidence. Similar 'positive feelings' were documented by Johnson et al. (2009), who suggests that these feelings might be triggered by the prospect of working on a real-world challenge, doing research and making a difference in the community. Generally, negative feelings such as 'Confusion' and 'Apprehension' were experienced at the beginning, mostly because students were not familiar with the business partners and their operations, found it difficult to fully understand CBL, and had never worked with a real-life challenge. Membrillo-Hernández et al. (2018) acknowledge that students may find

the uncertainty and self-learning involved in CBL to be challenging in the beginning. Binder et al. (2017) have reported a similar issue and recognize that some students find it difficult to understand the CBL approach. Sometimes, students also tend to resist the switch to a more active learning approach when they are used to traditional learning and adopting a more passive role (López-Fernández et al., 2020). Lara-Prieto et al. (2019) suggest that CBL interventions can improve students' ability to manage uncertainty by making them the protagonists of the learning process, and developing key competences through the exposure to real-life situations.

Interestingly, students who reported 'negative feelings' at the beginning, explained that those feelings gradually shifted as the term progressed and ultimately transformed into 'positive feelings', such as 'Sense of achievement', 'Relief' and 'Confidence'. Several reasons were given for this change. Some explained that confidence increased as a result of good teamwork. Once students had the chance to familiarize as a team and an effective team dynamic was accomplished, they became confident in their ability to finish on time and produce feasible solutions. They also mentioned that as their knowledge of their allocated business/challenge grew, through research and meetings with businesses, their confidence and motivation improved. Lastly, they suggested that confidence was also boosted by meeting with their tutors to clarify doubts and questions. In this regard, Tang and Chow (2020) emphasize the importance of regular formative assessment facilitated by tutors to monitor students' progress and struggles along the CBL intervention. Finally, students reported a sense of achievement after successfully completing the challenge. This is in line with findings from López-Fernández et al. (2020) who also observed an increase in intrinsic motivational levels after a CBL intervention, in particular, an increased sense of accomplishment.

Several aspects of the CBL approach were often discussed by students. In particular, aspects inherent to CBL, as an educational approach, were grouped under the 'Challenge-based learning' theme. Students seemed to value the use of a real-life challenge over a hypothetical situation or case study, which according to them, made the experience more interesting and professional. Students also reported that the opportunity to test problem-solving techniques in a real-life situation made them think outside the box for creative and realistic solutions that could be beneficial for society. This is in line with previous findings which suggest that students' satisfaction increases when faced with real-life problems (Membrillo-Hernández et al., 2018). Other studies have also documented positive impacts on technical skills (López-Fernández et al., 2020), motivation, engagement, complex thinking, and propensity to take risk (Yang et al., 2018).

Students reported that they were also able to further develop other skills, such as problem-solving and innovation. Existing literature suggests that these two skills can be improved significantly through the use of CBL (Johnson and Adams, 2011). Many students reflected on the importance of carrying out extensive research before attempting to find solutions to the challenges. This is an important aspect of CBL as it allows students to connect research to the challenges within their communities, which facilitates a stronger connection between what students learn is school and what they experience outside of it (Johnson and Adams, 2011). Students also enjoyed the innovative and creative side of the experience, and uniqueness. However, they also acknowledged that it took them a while to adjust to CBL as it is quite different from traditional learning and involves a higher level of uncertainty. Similar findings have been reported by Membrillo-Hernández et al. (2018) who suggests that students found the higher levels of uncertainty and self-learning very challenging. In the end, some of our students agreed that despite all the challenges the experience was rewarding, which can be an indication of flexibility and adaptability.

Conclusion

The proposed approach integrates theory and practice from OM and creative problem solving to support students in tackling real-life challenges in a creative and innovative way. Unlike other approaches such as PBL and POL, CBL provides the necessary guiding resources but allows a degree of uncertainty and freedom for students to exploit their creativity and innovation, which translate into a rewarding experience. Students reported improved knowledge of OM and industry 4.0 technologies. In particular, the students' experience was characterized by an enhancement in their ability to understand OM in real-life settings and the potential that industry 4.0 technologies represent in devising OM solutions. The proposed CBL approach was also conducive to students' development of 21st century skills, such as adaptability, collaboration, problem solving, communication, creativity and innovation. The implementation of our proposed CBL approach highlighted ways in which students can be better supported to fully benefit from CBL, from supporting team building to providing formative assessment regularly.

The main contribution of this research is the conceptualization, implementation and evaluation of a CBL approach for teaching OM. Even though the proposed CBL approach adopted 'Industry 4.0 technologies' as a theme, it can be adapted and applied using a different thematic. To the best of our knowledge, this is the first study to explore the potential benefits of CBL in OM education. Thus, our proposed approach and findings will serve as a reference for further implementation of CBL within OM education. Our findings suggest that there are many benefits from the timely introduction of CBL, both in terms of knowledge acquisition and the development of 21st century skills.

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References

Apple (2010) Challenge-Based Learning. A classroom guide. Retrieved from https://images.apple.com/education/docs/CBL_Classroom_Guide_Jan_2011.pdf. [Accessed January 2020].

Binder, F.V., Nichols, M., Reinehr, S. and Malucelli, A. (2017), "Challenge Based Learning applied to Mobile Software Development Teaching", The 30th IEEE Conference on Software Engineering Education and Training, Savannah, Georgia, 7-9 November.

Bowen, G. A. (2009) Document Analysis as a Qualitative Research Method. Qualitative Research Journal, 9(2), pp. 27 – 40.

Braun, V. and Clarke, V. (2006), "Using thematic analysis in psychology", *Qualitative Research in Psychology*, Vol. 3, No. 2, pp. 77-101.

Dutra Moresi, E.A., Oliveira Braga Filho, M., Alves Barbosa, J., Carmo Lopes, M., Alves Tito de Morais, M.A., Alves dos Santos, J.C., Pereira Borges, J.M., and Osmala Júnior W.A. (2017), O emprego do aprendizado baseado em desafios no desenvolvimento de aplicativos móveis. The use of Challenge Based Learning in mobile application development, 12th Iberian Conference on Information Systems and Technologies (CISTI), Lisbon.

Eisenhardt, K.M. (1989), "Building theories from case study research", *The Academy of Management Review*, Vol. 14, No. 4, pp. 532-550.

Gabriel, S.E., (2014), "A modified challenge-based learning approach in a capstone course to improve student satisfaction and engagement", *Journal of Microbiology and Biology Education*, Vol. 15, No. 2, pp. 316–318.

Gibbs, G. (1988), *Learning by doing: a guide to teaching and learning methods*, Further Education Unit, Oxford Polytechnic, Oxford, UK.

Guest, G., MacQueen, K. M., and Namey, E. E. (2011), *Applied thematic analysis*, Sage, Thousand Oaks, CA.

Hodder, I. (2000), "The interpretation of documents and material culture" in Denzin N. K. and Lincoln, Y. S. (Eds.), *Handbook of qualitative research* (2nd ed.), Thousand Oaks, CA: Sage, pp. 703–715.

Johnson, L.F. and Adams, S. (2011), Challenge Based Learning: The Report From the Implementation Project, The New Media Consortium, Austin, Texas.

Johnson, L.F., Smith, R.S., Smythe, J.T., and Varon, R.K. (2009), Challenge-Based Learning: An approach for our time, The New Media Consortium, Austin, Texas.

Lara-Prieto, V., Arrambide-Leal, E.J., García-García, R.M. and Membrillo-Hernández, J. (2019), "Challenge Based Learning: Competencies Development Through the Design of a Cable Transportation System Prototype", Proc. of the IEEE 11th International Conference on Engineering Education (ICEED2019), Kanazawa, Japan, 6-7 November.

Lincoln, Y.S. and Guba, E.G. (1985), *Naturalistic Inquiry*, Sage Publications, Newbury Park, CA.

López-Fernández, D., Salgado Sánchez, P., Fernández, J., Tinao, I., Lapuerta, V. (2020), "Challenge-Based Learning in Aerospace Engineering Education: The ESA Concurrent Engineering Challenge at the Technical University of Madrid", *Acta Astronautica*, Vol. 171, pp. 369-377.

Membrillo-Hernández, J., Ramírez-Cadena, M. de J., Caballero-Valdés, C., Ganem-Corvera, R., Bustamante-Bello, R., Ordóñez-Díaz, J.A.B., and Elizalde, H. (2018), "Challenge-Based Learning: The case of sustainable development engineering at the Tecnológico de Monterrey, Mexico City campus", *International Journal of Engineering Pedagogy*, Vol. 8, No. 3, pp. 137-144.

Nowell, L. S., Norris, J. M., White, D. E., and Moules, N. J. (2017), "Thematic Analysis: Striving to Meet the Trustworthiness Criteria", *International Journal of Qualitative Methods*, Vol. 16, No. 1, pp. 1-13.

Proctor, T. (2019), *Creative Problem Solving for Managers: Developing skills for decision making and innovation*, Routledge Ltd., London, UK.

Ringstaff, C. and Yocam, K. (1996), Integrating Technology into Classroom Instruction: An assessment of the impact of the ACOT teacher development center project. Apple Classrooms of Tomorrow. ACOT report #22. Retrieved from https://www.apple.com/euro/pdfs/acotlibrary/rpt22.pdf. [Accessed January 2020].

Slack, N. and Brandon-Jones, A. (2019), *Operations management*, Pearson Education, Harlow, UK.

Tang, A.C.Y. and Chow, M.C.M. (2020), "To evaluate the effect of challenge-based learning on the approaches to learning of Chinese nursing students: A quasi-experimental study", Vol. 85, No. 104293.

UNESCO (2015), *Rethinking Education. Towards a global common good?*, United Nations Educational, Scientific and Cultural Organization, Paris, France. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000232555/PDF/232555eng.pdf.multi [Accessed April 2020].

UNESCO (2017), *Training Tools for Curriculum Development: Developing and Implementing Curriculum Frameworks*, IBE-UNESCO, Geneve, Switzerland. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000250052/PDF/250052eng.pdf.multi. [Accessed April 2020].

World Bank (2019) The Changing Nature of Work. Retrieved from http://documents.worldbank.org/curated/en/816281518818814423/pdf/2019-WDR-Report.pdf. [Accessed April 2020].

Yanga, Z., Zhoua, Y., Chung, J.W.Y., Tanga, Q., Jiang, L. and Wonga, T.K.S. (2018), "Challenge Based Learning nurtures creative thinking: An evaluative study", *Nurse Education Today*, Vol. 71, pp. 40–47.