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Problem Based Learning: A facilitator of Computational Thinking

Tanja Svarre Jonasen, Sandra Burri Gram-Hansen
Aalborg University, Department of Communication and Psychology, Aalborg, Denmark
tanjasj@hum.aau.dk
burri@hum.aau.dk

Abstract: This paper explores and analyses the potential of Problem Based Learning (PBL) as a pedagogical framework for Computational Thinking (CT) in educations. CT skills are increasingly recognized as a necessity to all lines of study, as they not only facilitate digital proficiency, but potentially also a sense of computational empowerment and an ability to take a critical and constructive approach to applying computers when solving complex problems. The distinct focus on higher education is routed in theoretical as well as empirically based challenges, as this particular group of learners for the vast majority have started their education in a mainly analogue learning setting, yet now face employments with a much stronger demand for digital competences. With this paper, we aim to highlight the immediate benefits of PBL as a means to develop CT-skills as part of a higher education.

Keywords: Problem Based Learning, Computational Thinking, Collaborative Learning

1. Introduction

Digitalisation have and continuously will change both out professional and private lives (Bradley, 2000; Jan vom Brocke et al., 2018; Richter et al., 2018). These changes require a changed set of skills for citizens to become proficient users of digital resources along with critically and constructively applying technologies. The awareness of preparing pupils and students for this reality has been emphasised by the introduction of the notion of CT in schools, both K-12 and higher education (Witherspoon et al., 2017), though with an emphasis on K-12 (Kalelioğlu, 2018). CT represent the idea that learners are provided with a basic understanding of programming and computer modelling, along with tools for structured problem solving.

Much attention has been paid to K12 learners and the STEM disciplines in CT research, where initiatives have had varying length and learning activities (Kalelioglu et al., 2016; Shute et al., 2017). This paper focuses on CT in higher education, and in particular within the humanities, as higher educations are responsible for preparing students for the professional life after graduation. Thus, this is where CT skills should be combined with the disciplinary specialisation to meet the societal requirements for candidates.

Learning designs within CT are often associated with some sort of product development, where learning artefacts and tools are used to establish CT competences (Grover and Pea, 2013; Repenning et al., 2017). However, in order to gain a deeper understanding of CT problem solving which is required in higher education, alternative pedagogical approaches must be exposed. Czerkawski and Lyman (2015) have investigated the potential of game-based learning. The current paper explores, discusses, and analyses how PBL, and in particular AAU PBL comprises another alternative for supporting university students in obtaining CT skills. We argue that PBL may provide a stronger contextual and interdisciplinary understanding of the problem to be solved by means of CT skills. The following sections outline brief presentations of CT and PBL along with a discussion of the potential of PBL in CT. The theoretical basis of the paper is exemplified by a CT pilot study conducted in a PBL context under the faculty of humanities at Aalborg University, Denmark.

2. Theoretical underpinning

2.1. Computational Thinking

The aim of CT is to strengthen digital skills by including computing aspects in problem solving. Essentially, the purpose is to become able to reduce complex problems to smaller and manageable problems by approaching them with a computational mindset (Wing, 2006). The computational mindset can thus enable more efficient problem solving (Shute et al., 2017). A set of skills have been defined to identify the CT mindset. They include the ability to:

- Formulate problems in a way which enable us to apply computers in problem solving

- Organise and analyse data logically

- Represent data through appropriate abstractions in models and simulation

- Automate problem solving through algorithmic thinking

- Apply computers for problem identification, analysis and implementation of solutions

- Generalise and transfer problem solving to a broader variation of problems (Caspersen, 2017).

A different way of viewing CT is by the four distinct competences, that forms the concept, namely decomposition (breaking down systems or tasks into smaller units that enables explanation of the process to either a human or a computer), pattern recognition (spotting commonalities or differences that enables predictions or shortcuts), abstraction (identifying information that is necessary and unnecessary in problem solving) and algorithms (developing stepwise strategies for problem solving) (Wu and Richards, 2011).

The increased digitalisation in society along with Wing's (2006) paper on CT have increased the focus on CT in education both at K-12 level and in higher education. Across educational levels CT is seen as a concept that supports students in a more efficient and deeper understanding of the process of problem solving (Wing, 2014). Being a concept that emphasises problem solving, makes CT relevant to a wide range of disciplines (Yadav et al., 2011). Apart from having been implemented within the STEM area, disciplines like art, music and social sciences have also incorporated CT initiatives (Flórez et al., 2017; Wing, 2014). However, comparing the implementation across disciplines reveals some variation. To exemplify: in computer science decomposition is understood as defining objects and methods, while natural science sees it as the classification of species (Barr and Stephenson, 2011).

2.2. Problem based learning

PBL is known to be an exploratory approach to learning, where students learn through practical experience while working with real world problems. PBL differs from traditional learning approaches in using different learning activities that can qualify the students while exploring and solving identified problems. The aim is to provide the students with the possibility to gain new insights and competences in a nurturing learning environment that relates directly to the professional practice awaiting after their graduation (Kolmos, 1996; Kwan, 2012). Moreover, PBL provides better results than lecturing when it comes to students' critical thinking (Tiwari et al., 2006).

In this paper, we focus on the Aalborg University (AAU) PBL approach. Within this approach students builds up skills and insights by exploring and testing theories and methods in practice. Furthermore, AAU PBL enables students in building competences within communication, dissemination and group work (Kolmos et al., 2004). Three principles characterise the AAU PBL model; 1) the learning principle that learning is organised around problems, 2) the content principle that problem solutions arise from an interdisciplinary perspective, and 3) the social principle that learning takes place in teams and groups in the form of collaborative learning (Du and Kolmos, 2006; Kolmos et al., 2004). In collaborative learning students work together towards a common goal (Dillenbourg, 1999). Collaborative learning has been shown to improve students' ability to recall information longer (Johnson and Johnson, 1986) and increase their critical thinking (Gokhale, 1995).

Guided by these principles, students form groups to collaborate on real-world problems. Lectures, workshops, self-studies and project supervision facilitates the project process and the project process and eventually the research carried out is documented in a report. The process usually has a duration of 3-4 months (Ryberg et al., 2018). Below Figure 1 illustrates the general process.

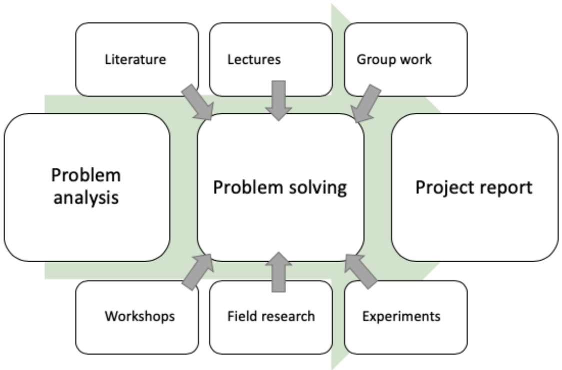

Figure 1 Illustration of the project process derived from Kjærsdam and Enemark (1994)

Although the AAU PBL model is known and recognised for having a strong potential, it also implies challenges. Thus, Huttel and Gnaur (2017) find that faculty staff experience a conflict between students' focus on exam results rather than on the project process. Across various university levels, there is a tendency to refer to the project reports as "the project" and considering the project process to be secondary to the documentation process and the exam grades. This finding is not surprising, considering that the focus on grades have been formed earlier in the schooling system and is what in most cases admit learners to a higher education. However, it is a problem, if students preparing for their professional life are unable to communicate their skills and competences and articulate the process followed in working with real-life problems. Huttel and Gnauer's (2017) recommendation based on their study is to focus more distinctly on the problem-solving process. In relation to the focus in the current paper, a stronger focus on the problem-solving process may also support the students' ability to increase their CT skills as increased problem-solving skills are also in the core of CT.

2.3. Strengthening CT with AAU PBL and collaborative learning

CT and PBL both represent concepts that aim at problem solving and problem understanding, but from different perspectives and with different purposes. However, the PBL approach holds a vast potential in acquiring CT competences for learners at different levels of education. With PBL's focus on enabling learners to explore and develop new skills and understandings in a nurturing environment while actively engaging in collaborative learning to solve real world problems, PBL may provide learners with a structure for acquiring lasting CT skills that represents critical thinking towards technology. A PBL approach to CT in education will contribute with a combined theoretical and practical experience for the learners, as they will have the PBL structure (Figure 1) to structure the identification and understanding of the problem at hand that enables a qualified problem solving, e.g. by applying CT skills in practice.

Understanding the problem prior to engaging in the problem-solving process requires learners to be able to critically reflect upon the distinct problem at hand as well as on the relation between the problem and the context. Iversen et al. (2018) point to the general lack of critical stance towards digitalized society in CT and argue that in educations contexts CT should extend the perspective from distinct skills to a wider focus on Computational Empowerment (CE). The authors point towards participatory design as a valuable contribution to CT in educational setting, pinpointing the importance of enabling children to make critical and informed decisions regarding the role of technologies in both professional and personal settings. In line with these recommendations, we argue that PBL provides a learning design framework, which through its distinct focus on e.g. group work and collaboration between students and supervisors, facilitates a learning process which goes beyond simply acquiring CT skills but also demands more in-depth reflections regarding the problem and the context in which it has emerged, which is required in higher education.

3. Putting theory to practice

In order to further explore and to exemplify how collaborative learning and PBL facilitate students in acquiring CT skills, we in this section refer to a pilot study conducted at Master of Science in Information Technology programs under the faculty of humanities (Cand.it). The study was conducted as a semi-structured investigation, where the initial goal was to explore whether CT also had potential in higher education and more distinctly in university programs under the faculty of humanities.

A distinct benefit of focusing on Cand.it program under the faculty of humanities, was that these programs focus distinctly on the challenges briefly presented in the introduction. The majority of students work towards a professional life where they will be expected to bridge between users and technology, and facilitate developers and designers in ensuring that the needs, values and requirements of the users are considered as new technologies are developed. Consequently, these students not only have a humanistic interest in technologies, they also engage actively in applying new technologies throughout their studies. Applying technologies when collecting data, analysing data, producing prototypes and eventually writing an academic report, is a natural part of the semester process. By reference to Barr and Stephenson (2011), recognition of the program being located under the faculty of humanities also influenced the understanding of CT skills and the expectations towards how CT skills were to influence the students.

20 students were included in the study and introduced to CT at two different occasions. First as part of the semester introduction and secondly at the end of the first semester. In both cases CT was mainly approached at a conceptual level, where the different CT skills provided the students with points for reflections and a vocabulary to explain own skills. Within the pilot study the aim was to benchmark the students' CT skills at the beginning of their studies and again after having completed a PBL process. The approach was based on the hypothesis that the students would extend their CT skills through the PBL structured semester and assessment focused on the students' ability to reflect upon and articulate their problem-solving process.

As the study was considered a preliminary step towards more stringent investigations of the relation between CT and PBL as well as the potential of CT in higher education, the study was designed to be naturally integrated into the already planned semester activities. It is with this in mind that we refer to the study as semi-structured. Rather than design distinct CT courses and evaluate the outcome of such, the aim was to investigate what the role of CT might be in the broader PBL process which as previously described comprises the centre of each semester at AAU. Data collection was primarily conducted through assignments which were designed to facilitate the involved students in reflecting upon own skills and competences and was consequently to some extent considered a secondary outcome. While follow up studies are naturally expected to be conducted more stringently, it was found beneficial to at this early stage remain as true as possible to the established PBL approach.

The initial benchmarking of the students' CT skills was done through a combination of workshop assignments. Having been introduced to both PBL and CT - with focus on decomposition, pattern recognition, abstraction, and algorithms, the students were on the first day asked to individually exemplify how the skills had been applied in their previous projects (for most students the bachelor project). Reflections concerning skills and competences was addressed once more on the second workshop day, were students were asked to start expressing skills in a competence structured CV template. This second assignment was designed so that it not alone facilitated the pilot study benchmarking process, but also provided the students with insights regarding own skills. This was considered important both when students form groups for the semester project, but also as preparation for internship applications and eventually applying for work.

The secondary benchmarking was conducted as part of the semester evaluation. At this point, the students were prompted to repeat the assignments from the workshop, but this time focusing on the project they had just completed. Again, focusing on the distinct CT skills, students were asked to assess how the skills had been applied through their project work. At this point, the aim was not alone to assess CT skills but also to prompt the students to reflect more critically about what skills they had applied and what competences they might still need building depending on their individual ambitions.

4. Preliminary findings

4.1. CT provides a vocabulary for problem analysis and problem solving

The data collected from the first benchmarking revealed that while all students were able to explain what they had done in their bachelor project, few students were able to reflect upon or even consider the individual CT skills. Students were able to mention distinct methods such as interviews for data collection, but unable to relate the method to the problem they had been solving or identify their approach as a specific competence. This indicated that the students lacked deeper understanding of the processes they had engaged in and potentially also a vocabulary to explain how they had managed the problem-solving process.

In contrast, the secondary benchmarking revealed that the students had acquired a much deeper understanding of their problem-solving process during their first PBL semester. Competences were richly expressed with reference to CT skills. E.g. specific methods were related to the process of decomposition. In consideration that CT had not been a distinct theme of the semester, but rather a perspective brought in for reflection purposes, it was not unexpected that the students did not demonstrate an in depth understanding of CT itself. None the less the development from the first to the second benchmarking was significant enough to motivate a further exploration of the potential of combing CT with a PBL approach. We found that the PBL approach had increased the students understanding of the different CT skills to the extent where they were able to relate them to their own practice. We credit this to the PBL approach as all students had previously completed a BA and as such were not new to academic work itself. Consequently, we find indications that CT may help address the previously mentioned issues presented by Huttel and Gnaur.

4.2. Digital competences were acquired through the PBL process and dependent on the problem at hand

Although the semester did include courses which focused on specific digital skills, the results of the secondary benchmarking indicated that computational competences were primarily acquired through the project work and driven by the problem that a group was working with. E.g. groups working with large batches of data would refer to digital resources for data management and analysis when explaining what CT skills, they had acquired during the semester. Likewise, critical reflections concerning different digital resources were based on practical experience gained through the project work, rather than on the introductions provided through lectures and workshops. This indicated that while the courses might inspire students to consider digital resources in their work, skills were based on practical experience. This was further supported by the second benchmarking in which the students emphasised the technologies which had been applied directly in their individual projects, and also the digital resources which had aided them when writing and preparing their semester report. Students recognized that besides from the problem they were addressing, another problem which could also be handled with CT skills was the documentation process. As exam reports are handed in digitally, students argued that CT skills such as decomposition and abstraction were also beneficial to the writing process and that digital resources such as reference management systems and collaboration-based writing platforms were examples of digital resources handling certain complex tasks and ensuring consistency. While it is debatable whether the examples qualify as CT skills, the arguments did support that the students had gained a stronger understanding of CT and of their own competences, and that this understanding had been acquired through their practical work.

4.3. CT in humanities calls for a stronger focus on Problem analysis

The conducted studies prompt us to further consider the PBL process itself and where in this process the CT perspective comprise a contribution. As mentioned, CT must be implemented and assessed in consideration of the research field in which it is applied. While Figure 1 visualises the PBL approach as comprised by three phases where problem solving is essential, it is particularly in humanities a case that the problem analysis is the essential part of a study. Analytically and in structured manner identifying a distinct problem in a specific context is enough to comprise a semester work. Consequently, it may be necessary to clarify that PBL activities such as group work, lectures and literature studies are of as much value to the problem-solving process and that CT skills may also serve a distinct purpose in the problem analysis phase. When considering CT in humanities, future research should include investigating if for instance a conceptual understanding of decomposition can contribute to a more structured identification of a problem, or if the PBL process benefits more from a more spontaneous curiosity amongst project group members.

5. Discussion

The preliminary findings presented in the previous section indicate that there indeed is a potential in further investigation of the relation between PBL and CT. It also gives reason to consider even further what CT skills comprise in higher education, how it distinguishes itself from CT in K12 programs and how these skills may be achieved through a PBL approach.

As previously explained, the aim of CT is to increase student's digital skills by actively applying digital resources in problem solving. Based on the insights gained both in theory and through the pilot study, we argue that the potential may go even further to the point where students who achieve CT skills, move from being digital literate, to also being able to critically assess complex digital systems and construct new digital solutions.

Based on Blooms taxonomy (Bloom, 1956), Anderson et al. (2001) present a revised model for thinking and learning. Lower levels of thinking progress from acquaintance to being able to apply, analyse and evaluate, while the highest level of thinking enables creation of new solutions. In relation to CT skills in the mentioned master level programs, CT was expected to enable students to engage in working with digital resources at a much higher and more reflective level. In accordance with Iversen et al. (2018) moving from being proficient users to also being able to critically assess existing technologies and construct new solutions.

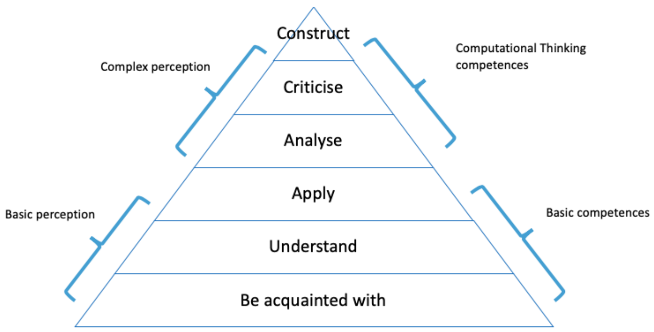

Figure 2 Revised version of Anderson and Krathwohl's (2001) model of Bloom's taxonomy

As visualized in Figure 2, CT was considered not solely an approach to problem solving but also an indication of a higher level of reflection and comprehension not only of technologies but also of one's own practice. CT skills were recognized as the students not simply being acquainted with digital resources but also being able to critically evaluate their possibilities and limitations when solving a distinct problem. At the same level of perception, students were expected to be able to assess their own practice analytically, critically and constructively.

As previously described, the AAU PBL approach is centred around real-world problems, identified and explored by the students in collaboration with supervisors. It is due to this focus on real world problems that it becomes a challenge to identify specific digital resources as essential to learners. As the digital world is rapidly changing, so do the required digital skills. It is thus we argue that critical and constructive skills become essential as it is within these levels of perception that students can identify and construct new solutions which fit their needs. This understanding of CT correlates well with the previously mentioned notion of CE, and furthermore facilitates an understanding of CT which is applicable across different levels of education. While the complexity of problems increases as students' progress from K12 educations into higher levels of education, so does the digital competences required to manage these problems. However, skills related to critically and constructively assessing a problem and solving it in a constructive manner remains essential at all levels.

One of the most important benefits of the AAU PBL approach may however be seen in the prolonged learning period, which in combination with the focus on collaboration is fundamental to the students reaching the higher levels of perception. Although shorter time spans do occur, most AAU PBL processes are conducted over a period of 3-4 months. The prolonged period of collaborative learning is identified as particularly beneficial, as it is during this process that students have time to discuss and reflect upon not only the problem but also their own process. Where shorter time spans tend to rush students into safe solutions and previously tested methods, the prolonged learning process grants the students with time to explore different approaches, and even time to fail and change direction.

6. Concluding remarks

In this paper we have suggested that the AAU PBL approach holds a potential in relation to CT in higher education. In continuation, we have argued towards an understanding of CT, which is applicable across different levels of education and in subjects, which go beyond the traditional STEM disciplines.

CT is identified as not only a practical set of skills but also a higher level of perception - a level of perception, which takes time and calls for an understanding of real-world problems. Whether the aim is for K12 learners to critically assess the possibilities and limitations of an iPad, or for learners at higher educations to be able to handle vast and complex amounts of data, each problem calls for practical experience with different digital resources in order for the students to construct the appropriate method for problem solving.

We argue that acquiring CT competences calls for prolonged use of technologies in educational settings, rather than brief introductions. The ability to critically assess the potential of a technology demands contextual understanding as well as practical experience with the technology. We relate this argument to the PBL understanding that identifying a real-world problem requires frustration or wondering about existing practice. Just as real-world problems come from actual insight, we argue that experience is fundamental to establishing CT skills. It is through experience that we become able to not only see the potential of a technology but also identify its limitations – and in a structured manner propose new and better solutions. Hence, CT also becomes essential not only to the core of humanities, but to all levels of education. With human society and culture in the heart of humanities it is inevitably necessary to move beyond digital literacy towards exploring and evaluating the impact of digital systems in our personal and professional lives.

The empirical study referenced in this paper indicated that CT skills in humanities not only provide the students with digital competences, but also a vocabulary which enables them to evaluate and explain their problem analysis and problem-solving process. This is an important impact of CT particularly for humanistic students who are expected to be able to bridge between users and developers and as such must be able to communicate clearly in both directions.

The AAU PBL approach does have much to offer, however challenges which call for further investigations remain. While the presented understanding of CT may be applicable across different levels of education, the potential of CT in higher education remains a challenge. While K12 students in many cases find themselves in the dawn of their education, students at higher levels of education are in the process of specialising themselves and preparing for professional practice. As such, the potential of CT skills must also be more distinctly related to potential professions. Moreover, if CT is recognized not only as digital skills applied in a problem-solving process, but also as a higher level of perception, there is a distinct need for appropriate methods for evaluation of CT skills.

7. References

Anderson, L.W., Krathwohl, D.R., Bloom, B.S., 2001. A taxonomy for learning, teaching, and assessing: a revision of Bloom’s taxonomy of educational objectives. Longman.

Barr, V., Stephenson, C., 2011. Bringing Computational Thinking to K-12: What is Involved and What is the Role of the Computer Science Education Community? ACM Inroads 2, 48–54.

Bloom, B., 1956. Taxonomy of Educational Objectives: The Classification of Educational Goals, Handbook 1: Cognitive Domain. McKay, New York.

Bradley, G., 2000. The information and communication society: how people will live and work in the new millennium. Ergonomics 43, 844–857.

Caspersen, M.E., 2017. Computational thinking, in: Gymnasiepædagogik. Kbh., pp. 470–476.

Czerkawski, B.C., Lyman, E.W., 2015. Exploring Issues About Computational Thinking in Higher Education. TECHTRENDS TECH TRENDS 59, 57–65.

Dillenbourg, P., 1999. Collaborative Learning: Cognitive and Computational Approaches. Advances in Learning and Instruction Series. Elsevier Science, Inc.

Du, X., Kolmos, A., 2006. Process competencies in a problem and project-based learning environment, in: Proceedings of the 34th SEFI Annual Conference: Engineering Education and Active Students. Presented at the SEFI Annual Conference, Uppsala.

Flórez, F.B., Casallas, R., Hernández, M., Reyes, A., Restrepo, S., Danies, G., 2017. Changing a Generation’s Way of Thinking: Teaching Computational Thinking Through Programming. Review of Educational Research 87, 834–860.

Gokhale, A.A., 1995. Collaborative Learning Enhances Critical Thinking. Journal of Technology Education 7, 22–30.

Grover, S., Pea, R., 2013. Computational Thinking in K–12: A Review of the State of the Field. Educational Researcher 42, 38–43.

Huttel, H., Gnaur, D., 2017. If PBL is The Answer, Then What is The Problem? Journal of Problem Based Learning in Higher Education 5.

Iversen, O.S., Smith, R.C., Dindler, C., 2018. From Computational Thinking to Computational Empowerment: A 21st Century PD Agenda, in: Proceedings of the 15th Participatory Design Conference: Full Papers - Volume 1, PDC '18. ACM, New York, NY, USA, pp. 7:1–7:11.

Jan vom Brocke, Maaß, W., Buxmann, P., Maedche, A., Jan Marco Leimeister, Pecht, G., 2018. Future Work and Enterprise Systems. Business & Information Systems Engineering 60, 357–366.

Johnson, R.T., Johnson, D.W., 1986. Cooperative learning in the science classroom. Science and children 24, 31–32.

Kalelioğlu, F., 2018. Characteristics of Studies Conducted on Computational Thinking: A Content Analysis, in: Khine, M.S. (Ed.), Computational Thinking in the STEM Disciplines: Foundations and Research Highlights. Springer International Publishing, Cham, pp. 11–29.

Kalelioglu, F., Gülbahar, Y., Kukul, V., 2016. A framework for computational thinking based on a systematic research review. Baltic Journal of Modern Computing 4, 583–596.

Kjærsdam, F., Enemark, S., 1994. The Aalborg Experiment: Project Innovation in University Education. Aalborg Universitetsforlag.

Kolmos, A., 1996. Reflections on Project Work and Problem-based Learning. European Journal of Engineering Education 21, 141–148.

Kolmos, A., Fink, F.K., Krogh, L., 2004. The Aalborg model: problem-based and project-organized learning, in: The Aalborg Model: Progress, Diversity and Challenges. Aalborg Universitetsforlag, Aalborg, pp. 9–18.

Kwan, A., 2012. Problem Based Learning, in: The Routledge International Handbook of Higher Education. Routledge, London.

Repenning, A., Basawapatna, A.R., Escherle, N.A., 2017. Principles of Computational Thinking Tools, in: Emerging Research, Practice, and Policy on Computational Thinking. Springer, Heidelberg, pp. 291–305.

Richter, A., Heinrich, P., Stocker, A., Schwabe, G., 2018. Digital Work Design. Business & Information Systems Engineering 60, 259–264.

Ryberg, T., Sørensen, M.T., Davidsen, J., 2018. Student groups as 'adhocracies' – challenging our understanding of PBL, collaboration and technology use, in: 7th International Research Symposium on PBL: Innovation, PBL and Competences in Engineering Education. Presented at the 7th International Research Symposium on PBL: Innovation, PBL and Competences in Engineering Education, Aalborg Universitetsforlag, pp. 106–115.

Shute, V.J., Sun, C., Asbell-Clarke, J., 2017. Demystifying computational thinking. Educational Research Review 22, 142–158.

Tiwari, A., Lai, P., So, M., Yuen, K., 2006. A comparison of the effects of problem-based learning and lecturing on the development of students' critical thinking. Medical Education 40, 547–554.

Wing, J.M., 2014. Computational Thinking Benefits Society. 40th Anniversary Blog of Social Issues in Computing.

Wing, J.M., 2006. Computational Thinking. Communications of the ACM 49, 33–35.

Witherspoon, E.B., Higashi, R.M., Schunn, C.D., Baehr, E.C., Shoop, R., 2017. Developing Computational Thinking Through a Virtual Robotics Programming Curriculum. ACM Transactions on Computing Education 18, 4:1–4:20.

Wu, M.L., Richards, K., 2011. Facilitating Computational Thinking through Game Design, in: Edutainment Technologies. Educational Games and Virtual Reality/Augmented Reality Applications, Lecture Notes in Computer Science. Presented at the International Conference on Technologies for E-Learning and Digital Entertainment, Springer, Berlin, Heidelberg, pp. 220–227.

Yadav, A., Zhou, N., Mayfield, C., Hambrusch, S., Korb, J.T., 2011. Introducing Computational Thinking in Education Courses, in: Proceedings of the 42Nd ACM Technical Symposium on Computer Science Education, SIGCSE '11. ACM, New York, NY, USA, pp. 465–470.