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How to link pedagogy, technology and STEM learning?

Margus PEDASTE[a*], Äli LEIJEN[a], Katrin SAKS[a], Ton de JONG[b] & Denis GILLET[c]
[a]*Institute of Education, University of Tartu, Estonia*
[b]*University of Twente*
[c]*École Polytechnique Fédérale de Lausanne*
*margus.pedaste@ut.ee

Abstract: Several studies show that technology has been actively used in everyday life, but much less in the learning context. When technology has been used by teachers, its main purpose has often been to engage students and motivate them to learn. In the Estonian context there are only 5% of students who use tablets and smartphones not only for searching for and sharing information but also for communication and content creation in the learning context. Linking technology use with different pedagogical approaches and measuring its effect on learning outcomes is much rarer. In several European research and development projects we have tested different pedagogic scenarios to use technology in STEM (Science Technology Engineering and Math) education. In these scenarios the inquiry-based learning approach has been supported with technology. In this paper we describe these cases and provide recommendations to improve learning process by linking pedagogy, technology and STEM learning more successfully. We propose that the main characteristics of new technology-enhanced learning environments have to enable self-directed computer-supported collaborative inquiry-based learning and the teachers have to support students' self-regulated learning, digital competence and autonomy in learning.

Keywords: STEM learning, technology-enhanced learning, digital competence, inquiry-based learning, self-regulated learning, computer-supported collaborative learning

1. Introduction

Publication of the 'Science Education Now: A renewed Pedagogy for the Future of Europe' report (Rocard et al., 2007) brought science and mathematics education to the forefront of educational goals for EU member states (following similar actions in the US in National Science Education Standards, 1996). The authors argued that school science teaching needs to be more engaging, apply inquiry and problem solving methods and designed to meet the interests of young people. It means science education (and also related studies in technology, engineering and math) need to be linked with pedagogical principles (pedagogy) and opportunities available thanks to developments in technology-enhanced learning (technology). According to the report, the origins of the alarming decline in young people's interest in key science studies and mathematics can be found, among other causes, in the old fashioned way science is often taught at schools. The crucial role that positive contacts with science at a younger age have in the subsequent formation of attitudes toward science has been emphasised in many studies (e.g. PISA, 2006). However, traditional formal science education too often fails to foster these, affecting negatively the development of adolescents' attitudes towards learning science. Also, as Kinchin (2004) has pointed out, the tension created between objectivism (the objective teacher-centred pedagogy) and constructivism (the constructive and student-centred pedagogy) represents a crucial classroom issue influencing teaching and learning. The TIMSS (Third International Mathematics and Science Study) 2003 International Science Report (Martin et al., 2004) specifically documented that the three activities accounting for 57% of class time in European science classes were: teacher lecture (24%), teacher-guided student practice (19%), and students working on problems on their own (14%).

Later, OECD TALIS survey showed in 2013 that not much has changed. The teachers accept a student-centred social-constructivism belief but their pedagogical beliefs are not necessarily related to their instructional practices. About 94% of teachers found that their role is to facilitate students' own inquiry and a bit more than 93% of teachers believe that students should be allowed to think of solutions to practical problems themselves before the teacher shows them how they are solved but the two most often used practices in classroom are presenting a summary of recently learned content and checking students' exercise books or homework (TALIS survey, 2013). In contrast, there were only 38% of teachers who reported that their students use frequently ICT for projects or class work.

The use of technology in learning is often seen as a solution to give to students more autonomy over their learning and to engage them more but also to have a positive effect on learning outcomes (see Pedaste et al., 2016). Prensky (2001) have introduced the idea that new generation of learners are digital natives who capture the benefits of technology organically and start using technologies in different context without specific support. Unfortunately, the study of van den Beemt, Akkerman and Simons (2010, 2011) showed that this assumption is not true. They focused on differences in the students' use of ICT in everyday life for interchanging, browsing, performing, and authoring and found in cluster analysis four profiles of applying ICT: traditionalists, networkers, producers, and gamers. Most of the people were networkers (39%) or traditionalists (28%) and only 6% of them belonged to the group of producers. Similarly, we found in 2016 in our study that smart phones and tablets are actively used in learning context for searching and sharing information, collaboration and content creation only by 5% of students (Pedaste et al., 2017) even if the devices are owned by 97% of the students (Adov et al., 2017). Surprisingly, this study was done in Estonian context and Estonia is well-known as an e-country where people usually have a very positive attitude towards use of technologies and a lot of innovation is also done in schools (see Leijen et al., 2014, Pedaste et al., 2014) and where the Science Technology Engineering and Math (STEM) learning outcomes according to OECD PISA studies are also among the best ones in the world (see http://pisa.oecd.org/).

One of the reasons why the potential of technology hasn't opened enough is lack of autonomy. During the Soviet times until 1991 the autonomy of the schools and teachers was very low and since that Estonia's educational system has been reformed many times but some of these activities did not have positive effect on autonomy (see Leijen & Pedaste, in press). For example, the schools were often ranked in national newspapers based on their students' scores in national exams and these high-stake standardized tests decreased teachers' autonomy in deciding what and how to teach their students. Considering the average age of teachers in Estonia (48 years) the fear related to autonomy and self-directed learning and teaching still lasts in practice. If the teachers do not feel that they have autonomy, then it's difficult to give more autonomy to the learners as well. Only during the last decade, both the national curriculum and state exams have been changed. In addition to subject-oriented goals the general competencies have gained much more importance and teachers have more freedom to decide what and how to teach. The number of compulsory national state exams is reduced and in this way more autonomy in several subjects has been given to the teachers. In addition, inquiry-based learning approach is adopted in updating all STEM curricula and new national performance tests are focusing on inquiry skills rather than content knowledge. These changes provide a good basis for implementing several other changes to link the newest pedagogical approaches with technology-enhanced learning to improve STEM learning.

In conclusion it's evident that there is a need to improve both science education and digital competence and teachers are as pedagogical agents who need guidelines for successful integration of technology-enhanced learning and STEM learning to change their instructional practices. Therefore, we analyse several cases where technology-enhanced STEM education has been in focus of international projects and provide guidelines for improving teachers' professional development to link pedagogy, technology and STEM learning more successfully.

2. Pedagogical approaches

The main underlying pedagogical approaches used recently in developing technology-enhanced learning in STEM education are self-regulated learning and inquiry-based learning. Often these are linked socio-constructivism indicating that individuals should learn how to regulate their learning in a group of learners and how to benefit from discussions on an inquiry task. As a result, we support the idea of developing learning environments that enable self-directed computer-supported collaborative inquiry-based learning. Next, the pedagogical approaches of self-directed learning, inquiry-based learning and computer-supported collaborative learning are introduced.

2.1. Self-regulated learning

The concept of self-regulated learning has been described through different definitions and models. What most of the theories agree about is that self-regulated learning is a constructive process whereby learners regulate different cognitive, metacognitive, motivational, volitional and behavioural processes during their learning (Winters et al., 2008). Pintrich (2000) drawing on Zimmerman's cyclical three-phase model, formulated his definition of academic self-regulation as an active, constructive process whereby learners set goals for their learning and attempt to monitor, regulate and control their cognition, motivation, and behaviour, guided and constrained by their goals and contextual features on the environment.

Learners with good self-regulated learning skills are able to use efficient learning strategies independently and control their learning process. It is especially important when a big part of learning takes place outside the traditional classroom, in web-based learning environments, at the workplace or in real-life situations. There is a variety of perspectives on self-regulated learning which incorporate individual self-regulated learning, co-regulation and socially shared regulation of learning (SSRL) (Hadwin et al., 2000) in different educational contexts. The three components of self-regulated learning – motivation, cognitive and metacognitive learning strategies are not static traits but dynamic and contextually bound (Duncan & McKeachie, 2005). They are gradually growing as learners become more aware and confident about their learning and responsibility. This makes observing and measuring the improvement of self-regulated learning interesting and challenging.

Self-regulated learning skills with their components of cognition, metacognition and motivation are a necessary prerequisite for the development of self-directed life-long learner (Saks & Leijen, 2014). To become a successful life-long learner, a primary presumption of developing self-directedness is acquiring self-regulated learning strategies. The use of appropriate learning strategies improves proficiency and achievement, and enables learners to take ownership of their own learning by enhancing learner autonomy, independence and self-direction (Wong, 2011).

2.2. Inquiry-based learning

Inquiry-based learning is defined as a process of discovering new causal relations, with the learner formulating hypotheses and testing them by conducting experiments and/or making observations (Pedaste, Mäeots, Leijen, & Sarapuu, 2012). It is important that the learner is active and takes responsibility in discovering knowledge that is new to him or her (de Jong & van Joolingen, 1998). Thus, by the nature inquiry-based learning is an approach where the main principles of self-regulated learning are applied. In order to guide this self-regulated process inquiry has been often divided into different phases which could be applied in many cycles. Pedaste et al. (2015) made a systematic literature review to describe the diversity of these phases and cycles. Based on analysis there was synthesized an inquiry cycle that combines the strengths of existing inquiry-based learning frameworks. This has been later used as a pedagogical framework in some of the projects described as cases in the current paper. They found in 32 articles 109 different terms for inquiry phases. Based on the analysis these were combined five general phases and some sub-phases in three of them.

According to Pedaste et al. (2015) inquiry learning starts with Orientation phase. In this phase learners get to know something about the problem situation and identify the problem. The second phase is Conceptualization. In this phase learners define the problem by collecting more information in order to formulate research questions and/or hypotheses. Depending on the outcome of the conceptualization phase there are two different pathways available in Investigation phase which is the third general phase. If the students formulated a research question, then they proceed with Exploration sub-phase where they systematically collect data to answer that question. If the learner formulated a hypothesis, then an experiment should be designed for data collection. In both cases the data should be analysed and interpreted in order to proceed to the fourth general phase which is Conclusion. According to this framework the fifth phase – Discussion – is not after the other four but in parallel with them. In Discussion all activities and outcomes of the other phases or these of whole inquiry process are communicated to peer students or others and reflected systematically in order to learn from the learning process. While discussion is one of the general phases of inquiry-based learning, we should they and collaboration a mandatory activity in inquiry-based learning. This leads us to the approach of computer-supported collaborative learning.

2.3. Computer-supported collaborative learning

What is CSCL, link to digital competence (again, self-directedness is needed) . There is no doubt that inquiry-based learning is at least in the context of STEM education more effective than other more traditional approaches. This has been revealed in several meta-analyses (see Alfieri, Brooks, Aldrich, & Tenenbaum, 2011; Furtak, Seidel, Iverson, & Briggs, 2012). The benefits of inquiry learning have been discussed for long time even though it was argued already more than 50 years ago that not all topics should be learned in this way (Taba, 1963). However, recent studies also show that technological advancements can increase the success of inquiry-based learning even more (de Jong, Sotiriou, & Gillet, 2014), especially if specific guidance is available (see Lazonder & Harmsen, 2016).

In order to apply inquiry-based learning in technology-enhanced environments digital competence is needed and might give some structure for guiding learners. According to a European framework of digital competence (Vuorikari, Punie, Carretero, & van den Brande, 2016) there are five competence areas that could be differentiated in digital competence: (i) information and data literacy, (ii) communication and collaboration, (iii) digital content creation, (iv) safety, and (v) problem solving. In each of these competence areas more specific competences (21 in total) are described. Most of these competences are needed in all general inquiry phases; however, the competence area Communication and collaboration provides some basis for computer-supported collaborative learning. The specific competences in this area are (i) interacting through digital technologies, (ii) sharing through digital technologies, (iii) engaging in citizenship through digital technologies, (iv) collaborating through digital technologies, (v) netiquette, and (vi) managing digital identity. This list shows clearly that there is no need to develop digital competence in separation from many other learning activities but digital competence is just a model that could be easily integrated in computer-supported collaborative learning process and also in the self-regulated inquiry-based learning context.

3. Cases

3.1. SCY project

The SCY (Science Created by You, http://scycom.collide.info) was a project financed by European Commission's 7th Framework Programme to develop a flexible, open-ended learning environment that engages and empowers adolescent learners. The project lasted from 2008 to 2012. The SCY project started from a social constructivist approach by letting the learners to complete different missions in a web-based learning environment SCY-Lab while interacting with other students (de Jong et al., 2010). The central idea of SCY was that students learn by creating artefacts that could be developed by the ones developed by other learners and found in a repository. These were called Emerging Learning Objects (ELOs). The artefacts (products) produced in the learning process where for example pieces of texts (e.g. research questions), datasets (from real or virtual environments), or even physical products like a model of a house. SCY-Lab provided adaptive support for learning activities through providing students with pedagogical scaffolds, collaboration facilities, peer assessment, and social tagging tools. It also enabled to combine physical and online activities in a blended learning process so that different offline activities could be guided by pedagogical scenarios presented online.

A good example of a SCY blended learning mission is SCY Eco Mission (Pedaste, de Jong, Sarapuu, Piksööt, van Joolingen, & Giemza, 2013). This primarily for learning ecology by combining hands-on data collection and working in the SCY-Lab learning environment. On this mission students have to improve water quality of a freshwater lake. In order to do this, students follow four predefined inquiry cycles on related topics: (i) the role of light in the level of photosynthesis, (ii) the concept of pH and pH changes in a water body, (iii) the influence of nutrient concentration on primary production, and (iv) relations between trophic levels in an ecosystem. What we see already in this project, is the integration of pedagogical framework and technology-enhanced learning environment. However, the sequence of activities on the missions was quite pre-defined and there was not much autonomy for students to adapt the experiments according to their own ideas. Indeed, there were available several tools and even pedagogical agents to support collaboration between students (collaborative content creation and chat related to different ELOs) but in practice there were often technical issues that did not allow to use SCY-Lab by wider audiences. This project developed a prototype for learning STEM in a technology-enhanced learning environment but it got evident that collaboration might be still too demanding at this time. Therefore, this learning environment was tested only in small scale.

3.2. Go-Lab and Next-Lab projects

The Go-Lab (Global Online Science Labs for Inquiry Learning at School) project (http://www.go-lab-project.eu), is a European Commission financed project that lasted from 2012 to 2016. The aim of this project was to increase the use on online science laboratories (remote and virtual labs) in school education at ages from 10 to 18. This environment has been now used by thousands of schools with many classes. In this project we also developed the inquiry-based learning cycle that was introduced previously and later used in the Next-Lab and Ark of Inquiry project.

In the project was created a technology-enhanced portal (http://gloabz.eu) that allows searching for hundreds of online labs that could be combined with more than 40 inquiry learning applications in order to build Inquiry Learning Spaces (ILSs). ILSs support particular lesson scenarios that are developed using the inquiry cycle as a guide. In this way Go-Lab is a good example case for combining inquiry-based learning and technological tools. The inquiry cycle is provided for instructional designers (who might be teachers) as a template of the ILS where all general phases are presented as separate spaces. For students these are presented as tabs where pages with phase-specific guidance, assignments and tools are provided. For example, in the conceptualisation phase apps like Hypothesis Scratchpad Concept Map could be used. In all phases could be used some general apps like Shared wiki, Teacher feedback, Quiz tool, Quest. These tools already give some possibilities for interaction between the learners or between learners and teachers; however, collaboration was not the main focus on Go-Lab project. Indeed, the project provided good possibilities for collaboration between teachers – the teachers were supported in building a community that could develop new ILSs, share these with each other, and give some advice to others if one has an issue. The community of teachers developed hundreds of ILSs that cover wide variety of topics to learn STEM subjects.

The Go-Lab project found its continuation in European Commission financed Next-Lab project (Next Generation Stakeholders and Next Level Ecosystem for Collaborative Science Education with Online Labs, http://project.golabz.eu). This project started in January 2017 and lasts until the end of 2019. The main improvement the project is aimed for is focusing clearly on collaboration. It means that the existing Go-Lab portal is updated that special focus is set on 21st century collaboration and reflection skills and new tools for self- and peer-assessment are provided. In addition, there will be created collaborative spaces where students could work in teams on research projects. To date there are eight apps supporting learners' collaboration, e.g. Padlet or SpeakUp app. The first one allows to create a wall within an inquiry space where text, picture, videos, audio, and hyperlinks could be easily organised in a cloud-based environment. SpeakUp is asocial discussion tool that allows to create a chat room where messages could be anonymous if necessary. In addition, there is also possible to rate the messages or to create simple polls. For teachers there is created the possibility to create ILSs collaboratively. However, they could also use several learning analytics apps to learn more about students' learning and to support their learning process appropriately. The important message from the Next-Lab case is that technology-enhanced learning is moving towards computer-supported collaborative learning.

3.3. Ark of Inquiry project

The Ark of Inquiry project (http://arkofinquiry.eu) is again one more European Commission financed project to support STEM learning. This started in 2014 and will finish in 2018. In this project the pedagogical framework developed in Go-Lab project is implemented and applied for teacher training but first linked with Responsible Research and Innovation (RRI) concept. RRI is a concept that is getting more and more attention in guiding the research and development aims in Europe. One of the best definitions of this have been given by Schomberg (2011, p. 9): "Responsible Research and Innovation is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view on the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society)." In order to specify this concept more for the project, a literature review was done. According to this we could differentiate six dimensions of RRI: (i) inclusion, (ii) anticipation, (iii) responsiveness, (iv) reflexivity, (v) sustainability, and (vi) care (Burget, Bardone, & Pedaste, 2016). Emergence of these dimensions shows very clearly that in collaboration we have to keep in mind and support several aspects and not only between students but according to RRI approach learning should happen in collaboration with the whole society.

Thus, the Ark of Inquiry project aims to create a "new science classroom", one which would provide more challenging, authentic and higher-order learning experiences and more opportunities for pupils to participate in scientific practices and tasks, using the discourse of science and working with scientific representations and tools in collaboration with peer students but also in collaboration with science centres and researchers. Therefore, there has been developed a platform (http://arkportal.eu) through which carefully selected inquiry-based activities will be made widely available across Europe and beyond. This platform will link together inquiry-based activities, learners and supporters (teachers, university students, researchers, staff of museums and universities). To support teachers, the Ark of Inquiry project provides face-to-face training for teachers so that they will be able to support and motivate the pupils in their inquiry-based learning activities.

4. Discussion and recommendations

The cases introduced in this paper give an idea about the changes in approaches to link pedagogical principles with technology-enhanced learning environments for STEM learning during the last 10 years. All these projects are European-wide projects where in each have participated institutions from more than 10 countries. Most of the projects have targeted thousands of students in hundreds of schools. Therefore, these cases represent major movements in Europe and are a good basis for generalisations.

First, we see that in all these projects there have been used a pedagogical scenario (usually inquiry-based learning) that is then enhanced by technological tools. The scenario-based approach has been increasingly used in linking pedagogy and technology-enhanced learning during the last decade (see de Jong et al., 2012; Lejeune et al., 2009). Therefore, our first recommendation for instructional designers is not to focus too much on the technological tools available on the market but on the pedagogical needs.

Second, we saw that autonomy is more and more given to the students and also teachers get in recent projects more possibilities for designing new learning scenarios according to their specific goals. This movement supports both learners' and teachers' proficiency while they take ownership of their own learning by enhancing autonomy, independence and self-direction (Wong, 2011). Therefore, our second recommendation is to support students' skills for self-directed learning more systematically. This is not something new while already more than 40 years ago Malcolm Knowles (1975) envisioned "a process in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating their learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes" (Knowles, 1975, p. 18). However, it's interesting that decades later we are still discussing similar ideas. The reason for that might be the new affordances that have been opened by technology, which should be used according the pedagogical goals.

What is similar in all projects reviewed in the current study, is reuse of existing learning objects (for a definition see Cisco Systems, 1999) as it is expected in case of a constructivist approach. Therefore, the third recommendation would be to give some focus on digital competence to use technology-enhanced tools not only for searching and sharing information but also for communication and collaboration in content-creation (for a framework of digital competence see Carretero, Vuorikari, & Punie, 2017). This recommendation is valid for both learners and teachers while both of them could create artefacts that could be re-used by themselves or others. RRI approach introduced in the Ark of Inquiry project (see Burget et al., 2017) takes this responsibility in sharing materials and knowledge beyond the classroom by integrating different stakeholders in the learning process.

Fourth, an interesting change has been seen in supporting collaboration between learners. Although there was a willingness to use a collaborative learning approach already ten years ago it seems that only in the last years the available technological tools provide a stable solution to support collaboration in many different ways. Several apps in the Next-Lab learning environment offer many possibilities for collaborative content creation that is supported by online discussion and sharing information in a problem-solving process. Indeed, it seems that the best solution is to combine different learning objects (e.g., online labs, learning apps) rather than designing very complex learning environments that cannot be customized and adapted by the teachers and learners. This might be one of the reasons why the prototype of the SCY-Lab was not ready for scaling up its use in many schools.

On the basis of these findings and recommendations we can also draw some guidelines for teachers to prepare their students for a self-regulated collaborative STEM learning process in computer-supported learning environments. First, the students need systematic support in developing their competence for self-regulated learning. Second, the students also have to get systematic support for developing their digital competence, especially in the competence areas communication and collaboration and digital content creation. Third, the teachers should keep in mind that a pedagogical framework, e.g. inquiry-based learning framework should be applied so that it allows self-directed and collaborative learning and leaves to the learners’ autonomy in selecting different technological tools according to their learning goals and preferences. However, these developments have to be supported by relevant studies on teachers’ readiness to use technology and both learners’ and teachers’ acceptance of technology (see the TRAM model by Lin, Shih, & Sher, 2007). In the Estonian context our studies show that the learners and teachers are willing to use technology and they have equipment but the missing validated pedagogical learning scenarios seem to be missing too often and it results in quite rare use of modern technologies like smart phones and tablets in learning context (Pedaste et al., 2017). Therefore, the future studies have to focus more on teachers’ and learners’ practices on using learning scenarios where pedagogy and technology are linked to support learning for example in STEM context.

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References

Adov, L., Must, O., & Pedaste, M. (2017). Attitudes Towards Mobile Devices in Estonian Basic Education: Using the Framework of the UTAUT Model. In: Zaphiris, P.; Ioannou, A. (Ed.). *Learning and Collaboration Technologies* (319−329). Springer.

Alfieri, L., Brooks, P. J., Aldrich, N. J., & Tenenbaum, H. R. (2011). Does discovery-based instruction enhance learning? *Journal of Educational Psychology*, *103*, 1–18. doi:10.1037/a0021017.

Burget, M., Bardone, E. & Pedaste, M. (2017). Definitions and conceptual dimensions of responsible research and innovation: A literature review. *Science and Engineering Ethics*, *23*(1) https://doi.org/10.1007/s11948-016-9782-1

Carretero, G. S., Vuorikari, R., & Punie, Y. (2017). DigComp 2.1: The digital competence framework for citizens with eight proficiency levels and examples of use. EUR – Scientific and Technical Research Report. Information Society. Publications Office of the European Union.

Cisco Systems. (1999). *Reusable information object strategy*. Retrieved from https://www.google.ee/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwjri9ucm6XWAhXoQZoKHSrpAegQFggkMAA&url=https%3A%2F%2Fwww.mindmeister.com%2Fgeneric_files%2Fget_file%2F519411%3Ffiletype%3Dattachment_file&usg=AFQjCNGCCGoqPh1wfDdAVth4VZuXZNw8HQ

de Jong, T., Sotiriou, S., & Gillet, D. (2014). Innovations in STEM education: The Go-Lab federation of online labs. *Smart Learning Environments*, *1*, 1–16.

de Jong, T., & van Joolingen,W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research*, *68*, 179–202. doi:10.2307/1170753.

de Jong, T., van Joolingen, W., Giemza, A., Girault, I., Hoppe, U., Kindermann, J., Kluge, A., Lazonder, A., Vold, V., Weinberger, A., Weinbrenner, S., Wichmann, A., Anjewierden, A., Bodin, M., Bollen, L., d'Ham, C., Dolonen, J., Engler, J., Geraedts, C., Grosskreutz, H. ... van der Zanden, M. (2010). Learning by creating and exchanging objects: The SCY experience. *British Journal of Educational Technology*, *41*(6), 909−921.

de Jong, T., Weinberger, A., Girault, I.; Kluge, A., Lazonder, A. W., Pedaste, M., Ludvigsen, S., Ney, M., Wasson, B., Wichmann, A., Geraedts, C., Giemza, A., Hovardas, A., Julien, R., van Joolingen, W. R., Lejeune, A., Manoli, C., Matteman, Y., Sarapuu, T., Verkade, A. ... Zacharia, Z. C. (2012). Using scenarios to design complex technology-enhanced learning environments. *Educational Technology Research & Development*, *60*(5), 883−901.

Duncan, T. G. & McKeachie, W. J. (2005). The making of the Motivated Strategies for Learning Questionnaire. *Educational Psychologist, 40*(2), 117–128.

Furtak, E. M., Seidel, T., Iverson, H., & Briggs, D. C. (2012). Experimental and quasi-experimental studies of inquiry-based science teaching. *Review of Educational Research*, *82*, 300–329. doi:10.3102/0034654312457206.

Hadwin, A. F., Järvelä, S. & Miller, M. (2000). Self-regulated, co-regulated, and socially shared regulation of learning. In M. Boekaerts, P. Pintrich & M. Zeidner (Eds), *Handbook of self–regulation* (pp 65–84). San Diego: Academic Press.

Kinchin, I. M. (2004). Investigating students' beliefs about their preferred role as learners. *Educational Research*, *46*(3), 301–312.

Knowles, M. S. (1975). *Self-Directed Learning: a guide for learners and teachers*. New York: Associated Press.

Lazonder, A. W., & Harmsen, R. (2016). Meta-analysis of inquiry-based learning: Effects of guidance. *Review of Educational Research*, *86*(3), 681–718.

Leijen, Ä., Allas, R., Toom, A., Husu, J., Marcos, J. J. M., Meijer, P., Knezic, D., Pedaste, M. & Krull, E. (2014). Guided Reflection for Supporting the Development of Student Teachers' Practical Knowledge. *The European Procedia Social and Behavioral Sciences*, *112*, 314–322.

Leijen, Ä., & Pedaste, M. (in press). Pedagogical beliefs, instructional practices and opportunities for professional development of teachers in Estonia. In H. Niemi, A. Toom, A. Kallioniemi, & J. Lavonen (Eds.) Teachers role in a global changing world. Sense Publishers, Rotterdam, the Netherlands.

Lejeune, A., Ney, M., Weinberger, A., Pedaste, M., Bollen, L., Hovardas, T., Hoppe, U., & de Jong, T. (2009). A graphical modeling language for computer-based learning scenarios. Proceedings of the IEEE International Conference on Advanced Learning Technologies: The 9th IEEE International Conference on Advanced Learning Technologies; Riga, Latvia; 15–17 July 2009. Ed. Aedo, I.; Chen, N.-S., Kinshuk, Sampson, D., & Zaitseva, L. IEEE, 734−735.

Lin, C.-H., Shih, H.-Y., & Sher, P. J. (2007). Integrating technology readiness into technology acceptance: The TRAM model. *Psychology & Marketing*, *24*(7), 641–657.

Martin, M. O., Mullis, I. V. S., Gonzalez, E. J., & Chrostowski, S. J. (2004). *TIMSS 2003 International science report*. Boston, MA: TIMSS & PIRLS International Study Center, Lynch School of Education, Boston College.

National Science Education Standards (1996). Board on Science Education (BOSE).
Pedaste, M., de Jong, T., Sarapuu, T., Piksööt, J., van Joolingen, W. R., & Giemza, A. (2013). Investigating ecosystems as a blended learning experience. *Science*, *340*(6140), 1537−1538.
Pedaste, M., Lazonder, A., Raes, A., Wajeman, C., Moore, E., & Girault, I. (2016). Empowering Science Teachers Using Technology-Enchanced Scaffolding to Improve Inquiry Learning. In: Eberle, J.; Lund, K.; Tchounikine, P.; Fischer, F. (Ed.). Grand Challenge Problems in Technology-Enhanced Learning II: MOOCs and Beyond (pp. 17−20). Springer.
Pedaste, M., Must, O., Leijen, Ä., Mäeots, M., Siiman, L., Kori, K., & Adov, L. (2017). Nutiseadmete kasutamise profiilid loodusainete ja matemaatika õppimise kontekstis. *Eesti Haridusteaduste Ajakiri*, 5 (1), 99−129.
Pedaste, M., Mäeots, M., Leijen, Ä., & Sarapuu, S. (2012). Improving students' inquiry skills through reflection and self-regulation scaffolds. *Technology, Instruction, Cognition and Learning*, *9*, 81–95.
Pedaste, M., Mäeots, M., Siiman L. A., de Jong, T., van Riesen, S. A. N., Kamp, E. T., Manoli, C. C., Zacharia, Z. C., & Tsourlidaki, E. (2015). Phases of Inquiry-based Learning: Definitions and the Inquiry Cycle. *Educational Research Review*, *14*, 47–61.
Pedaste, M., Pedaste, K., Lukk, K., Villems, P., & Allas, R. (2014). A Model of Innovation Schools: Estonian Case-study. *The European Procedia Social and Behavioral Sciences*, *112*, 418–427.
Pintrich, P. (2000). The role of goal orientation in self-regulated learning. In M. Boekaerts, P. Pintrich, & M. Zeidner (Eds), *Handbook of self–regulation* (pp 451–502). San Diego: Academic Press.
PISA 2006 Science Competencies for Tomorrow's World. Retrieved August 18, 2017 from: http://www.pisa.oecd.org
Prensky, M. (2001). Digital natives, digital immigrants. On the Horizon, 9 (5). https://www.marcprensky.com/writing/Prensky%20-%20Digital%20Natives,%20Digital%20Immigrants%20-%20Part1.pdf. https://doi.org/10.1108/10748120110424816
Rocard, M., Csermely, P., Jorde, D., Lenzen, D., Walberg-Henrikson, H., & Hemmo, V. (2007). *Science education now: A renewed pedagogy for the future of Europe*. Brussels: European Commission: Directorate-General for Research.
Saks, K., & Leijen, Ä. (2014). Distinguishing Self-Directed and Self-Regulated Learning and Measuring them in the E-learning Context. *Procedia – Social and Behavioral Sciences*, *112*, 190–198.
Taba, H. (1963). Learning by discovery: Psychological and educational rationale. *Elementary School Journal, 63*, 308–316. doi:10.1086/460059
The OECD Teaching and Learning International Survey (2013). http://www.oecd.org/edu/school/talis.htm
van den Beemt, A. A. J., Akkerman, S., & Simons, P. R. J. (2010). The use of interactive media among today's youth: Results of a survey. *Computers in Human Behavior*, *26*(5), 1158–1165. https://doi.org/10.1016/j.chb.2010.03.022
van den Beemt, A. A. J., Akkerman, S., & Simons, P. R. J. (2011a). Considering young people's motives for interactive media use. *Educational Research Review*, *6*(1), 55–66. ttps://doi.org/10.1016/j.edurev.2010.06.002
von Schomberg, R. (Ed.). (2011). *Towards Responsible Research and Innovation in the Information and Communication Technologies and Security Technologies Fields*. Luxembourg: Publications Office of the European Union. http://ec.europa.eu/research/science-society/document_library/pdf_06/mep- rapport-2011_ en.pdf.
Vuorikari, R., Punie, Y., Carretero, S., & van den Brande, L. (2016). *DigComp 2.0: The digital competence framework for citizens. Update Phase 1: The Conceptual Reference Model*. Luxembourg Publication Office of the European Union. EUR 27948 EN. doi:10.2791/11517 http://publications.jrc.ec.europa.eu/repository/bitstream/JRC101254/lfna27948ene.epub
Winters, F. I., Greene, J. A. & Costich, C. M. (2008). Self-Regulation of Learning within Computer-based Learning Environments: A Critical Analysis. *Educational Psychology Review*, *20*, 429–444.
Wong, M. S-L. (2011). Language learning strategy use: a study of pre-service teachers in Malaysia. http://www.eric.ed.gov/PDFS/ED521415.pdf.