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Aksela, Maija

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Promoting Meaningful Science Teaching and Learning Through ICT in the Finnish LUMA Ecosystem

Maija Aksela[1,2], Jenni Vartiainen[1,2], Maiju Tuomisto[2], Jaakko Turkka[2], Johannes Pernaa[2] & Sakari Tolppanen[2]

[1] LUMA Centre Finland, University of Helsinki, Finland

[2] Unit of Chemistry Teacher Education, Department of Chemistry, University of Helsinki
Correspondence: maija.aksela@helsinki.fi

Abstract
Information and communication technology (ICT) has been successfully used to promote children's, youths' and teachers' competence in mathematics, science and technology in Finland through the LUMA Centre Finland. The LUMA ecosystem (LU stands for science and MA for mathematics) is a social innovation based on collaboration between 11 universities (including researchers and teacher trainers), educational administrations, the business sector, teachers, teacher associations, science museums and centers, families and the media. It is a Finnish model of how to promote LUMA learning, teaching and teacher training. One particular focus of the LUMA collaboration is to support the incorporation of information communication technology (ICT) into classroom practice, especially by supporting pre- and in-service teachers in building their technological pedagogical content knowledge (TPCK). This paper reviews some of the earlier research and development conducted by the LUMA Centre Finland on the incorporation of ICT into teacher training and non-formal science education. As an example, this paper summarizes the research done on molecular modeling, the microcomputer-based laboratory (MBL) in chemistry education and its' implications for teacher education, and virtual learning environments in science education. This paper also discusses how design-based research has been used as a successful research method to connect theory and practice and to develop pedagogical ICT innovations in science education. Some going-on research topics (e.g. MOOCs) are also presented

Introduction

The main aim of the LUMA Centre Finland is to promote a high level of knowledge in mathematics, science and technology for all and to ensure a sufficient number of professionals, specifically by aiding the incorporation of research-based practice into education. This is done by connecting formal, non-formal and informal education for children and youths between the ages of 3 to 19 as well as offering training to pre- and in-service teachers and collaborating with families. The LUMA Centre serves as the umbrella organization for 13 LUMA Centres in 12 Finnish universities to strengthen and promote their collaboration at both the national and international level. It utilizes its 11 visiting labs in mathematics, science and technology at various universities around Finland to promote collaboration between schools and develop pedagogical innovations in science education through design-based research (e.g. Vihma & Aksela, 2014).

One unique aim of the LUMA collaboration is to support the incorporation of information communication technology (ICT) into classroom practice at all levels, from kindergarten to university, by promoting teachers' professional development (CPD). The newest research on ICT use has been incorporated into teacher training in order to help teachers manage ICT in the 21st century. First, this means that teachers need to have and develop their technological knowledge (TK). Secondly, teachers need to understand how to use ICT to facilitate learning, or in other words, they need technological pedagogical knowledge (TPK). Thirdly, teachers need to know how to search for and present knowledge using ICT, meaning that they also need technological content knowledge (TCK). However, even these three factors alone are not enough for quality ICT-supported teaching. Therefore, LUMA teacher training emphasizes that teachers should have excellent technological pedagogical content knowledge (TPCK), thus integrating all the aforementioned types of knowledge. In practice, this means that teachers should possess a dynamic and transformative tacit knowledge of technology which is integrated into their pedagogical knowledge (PK) and content knowledge (CK) (Koehler, & Mishra, 2008; 2009; Chai, Koh, Tsai, & Tan, 2011; Rogers, & Twidle, 2013), as depicted in Figure 1.

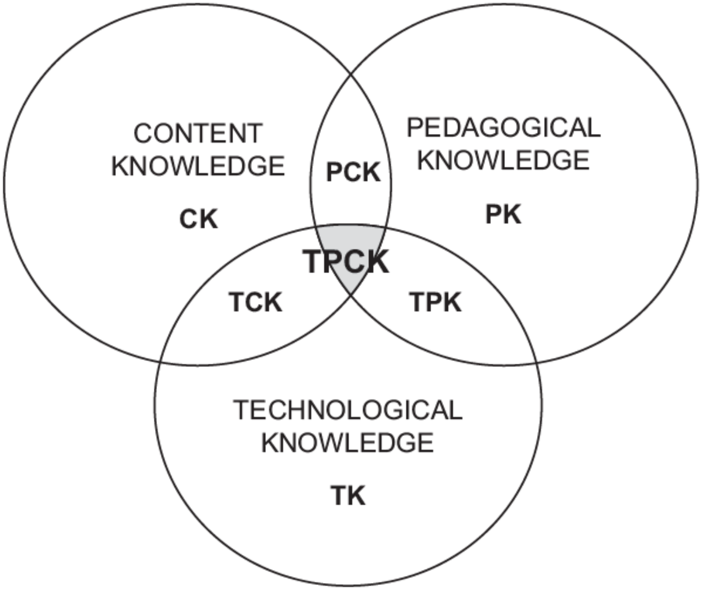

Figure 1: Definition of technological pedagogical content knowledge TPCK (Koehler, & Mishra, 2008, 13; 2009, 63)

The TPCK framework is based on the pedagogical approach known as "learning technology by design" which places emphasis on learner-centered learning-by-doing in authentic contexts. When this approach is applied to teacher training, teachers are engaged in authentic design activities related to educational ICT (Mishra & Koehler, 2006). The "learning technology by design" approach is based on the educational design research approach (e.g. Aksela, 2005; Pernaa & Aksela, 2013).

Science teachers have to stay up-to-date with the latest applications of educational technology and find the best ways to use them. The LUMA Centre Finland supports their lifelong learning through a continuum model (e.g. Aksela, 2010) that includes the following components: i) pre-service training, ii) an induction stage, and iii) in-service training. The base for lifelong learning is created during all levels of training for pre-service teachers. During their studies, pre-service teachers are provided with an excellent opportunity to practice interacting with children and youths by leading different LUMA activities. Authentic and regular experiences with students build skills to guide and manage the children and youths. In the induction stage that follows, newly graduated LUMA teachers collaborate actively and closely with their *Alma Mater*. The LUMA ecosystem's online services offer many opportunities for these newly-qualified teachers in terms of self-development and chances to network with other recent graduates. Further on in their career path, experienced LUMA teachers at school level receive support from various LUMA activities (webzines, newsletters, in-service training courses, consultation, webinars, MOOC et al.). To respond to the challenges of an ever evolving IT society, the LUMA Centre Finland organizes high-quality LUMA in-service training, in which ICT plays a significant role in supporting teachers' lifelong learning. These in-service training courses are also open to pre-service teachers, so that pre-service and in-service teachers can interact with and learn from one another. As there are frequently obstacles that prevent teachers attending these training courses in person, more and more in-service training is organized online via virtual learning environments (e.g. Vihma & Aksela, 2014).

Science teaching and learning through ICT

This chapter summarizes some of our earlier research on the incorporation of ICT into Finnish science education at school level and into teacher training, especially in the context of chemistry education.

The current state of using ICT in Finnish science education at school level

ICT can be seen as a novel way of pedagogical thinking that supports the use of various pedagogical and didactical methods in science education. Therefore, ICT has been used to support teaching and learning in mathematics, science and technology education in Finland since at least the 1980s. Furthermore, promoting the use of ICT in classroom practice is one of the central aims of the Finnish education policy designed by the National Board of Education (Opetushallitus, 2014; 2015).

Over the years, there have been many useful professional development projects to increase teachers TPCK and improve the use of ICT in science teaching in Finland (e.g. Aksela & Karjalainen, 2008; Lavonen, Juuti, Aksela, & Meisalo, 2006). As an example, an ongoing project, called LUMA SUOMI, supported by the Finnish Ministry of Culture and Education, aims to help integrate ICT into mathematics, science and technology education by teaching 6- to 16-year olds about programming and robotics. The LUMA Finland program intends to find novel and innovative tools and approaches to teaching practices, methods and learning environments. It is based on current research and it aims to provide practical action guidelines that can be employed in schools nationwide.

Since 1998, several studies have been conducted in Finland to examine how ICT is used in schools to promote science education (e.g. Aksela & Juvonen, 1999¸ Lavonen et al, 2006). The most recent survey (Helppolainen & Aksela, 2015) examined the opportunities and barriers that teachers encounter when implementing ICT use into science education. The study showed that TPCK training increases teachers' positive beliefs in the use of ICT in teaching and learning. Furthermore, although science teachers seem to have a decent skill level in using general software, their knowledge of science-specific software was often quite poor. Therefore, teachers seem to require more subject specific training on how to support students' learning through ICT To sum up, the survey concluded that the biggest barriers to ICT use were the lack of time, too large groups, the lack of TCPK and a lack of suitable software or materials (Aksela, & Lundell, 2007; Aksela, & Karjalainen, 2008; Helppolainen & Aksela, 2015). The research obtained from the Finnish teachers demonstrates that the benefits of using ICT in chemistry education lie in the diverse possibilities to enhance students' motivation and cognitive processes for higher order thinking skills (Pernaa, 2011).

The use of ICT in pre-service chemistry teacher education

As discussed, the LUMA Centre Finland supports teachers' lifelong learning in the context of ICT through a three-part continuum model (e.g. Aksela, 2010) centered on the following components: i) pre-service training, ii) an induction stage, and iii) in-service training For over ten years, TCPK has had a strong presence in teaching and research made/conducted by the Chemistry Teacher Education Unit in the Department of Chemistry at the University of Helsinki (e.g. Aksela 2005;

Aksela, & Lundell, 2008; Pernaa, & Aksela, 2009; Pernaa, 2011; Pernaa, Aksela, & Västinsalo, 2010).

On the base of earlier research and experiences, a TCPK strategy for chemistry teacher education was developed and piloted (see further on in the text for details). As the results demonstrate, providing TCPK in pre-service teacher education is the most effective way to enable teachers to use ICT skills. Other ways to enable the usage of these skills include offering in-service ICT training for teachers and teacher trainers, peer support and the introduction of quality tools (Ertmer, 1999; Ertmer, Ottenbreit-Leftwich, & York, 2006; Goktas, Yildirim, & Yildirim, 2009; Chai et al, 2011). ICT and real-situation teaching should also be combined in teacher education (Goktas et al, 2009). ICT training is most effective when it is integrated into pre-service teacher training courses. When trainee teachers are engaged in the planning and application of reasonable ICT-integrated lessons, both their basic skills (CK, PK and TK) and professional skills (TPK, TPCK) will develop (Angeli, & Valanides, 2009; Koehler, Mishra, & Yahya, 2007). The pre-service training stage must already concern itself with improving teachers' competency in the target skills and assuaging any negative attitudes and beliefs they may have (Ertmer et al, 2006). As teacher educators are role models for the pre-service teachers, they should serve as role models by integrating and applying ICT technology in their own courses and teaching (Goktas et al, 2009; Myllyviita, & Lavonen, 2014).

In Finnish pre-service teacher training, there is a strong desire to use ICT diversely and the students are highly motivated to use ICT in their own classrooms (Meisalo, Lavonen, & Sormunen, 2011). In general, Finnish teacher education plays a key role in training future teachers to skilfully follow the Finnish National Curricula and integrate with ICT. Objectives for TK and TPK should be included in course and degree aims in a cumulative way (Myllyviita, & Lavonen, 2014). When using factor analysis to research the effects of the different factors contributing to TPCK (N=343), Chai et al (2011) found the direct effect of subject specific content knowledge (CK) and technological pedagogical knowledge (TPK) on the development of TPCK to be of great significance. Technological content knowledge (TCK) for pre-service teachers can be supported and affirmed by providing students on pre-service education courses with opportunities to use the relevant ICT when teaching a specific topic (Goktas et al, 2009; Chai et al, 2011). In chemistry, for example, molecular modeling, electrolysis simulation and microcomputer-based laboratory (MBL) make use of this kind of ICT (see Chapter later on).

Based on the previous research and 21st century ICT skills, an ICT strategy for chemistry teacher education was developed during the spring of 2014 and piloted in the fall of 2014. The multifaceted use of ICT has important significance for the education of chemistry teachers at the University of Helsinki In the Chemistry Teacher Education Unit, students are educated to become skilled teachers who are ready to face the demands of school environments in the near future. Good ICT skills represent a key element of this goal, meaning that it is essential to supply students with various opportunities to continuously develop their ICT skills, to use digital teaching tools and applications competently (Tuomisto, Aksela, & Jääskeläinen, 2015).

All chemistry students learn basic ICT skills by completing the course *ICT License* (3 ECTS). The developed ICT strategy featured 20 subcategories (see Table 1) included in the courses offered by the Chemistry Teacher Education Unit (13 courses, course *ICT License* excluded). Nine of these courses are mandatory and the other five are voluntary for chemistry teacher students. In each of these 13 courses, one to three of the ICT strategy subcategories have been selected to be integrated into the course. Additionally, chemistry teacher students will train and apply their ICT skills to pedagogical courses under the guidance of experts in science pedagogy and in real school environments under the guidance of chemistry teachers from the practice school (Tuomisto, Aksela, & Jääskeläinen, 2015).

Table 1: Subcategories included in the ICT strategy of the Chemistry Teacher Education Unit. (Grey-colored sub-categories and courses were included in the applied ICT strategy research.)

Subcategories in ICT strategy	Integrated into course/courses	Credits
1 Basic skills	ICT license (*and applications on all courses)*	3
2 Face your classroom	*(on all courses: e.g. course platforms)* Introduction to chemistry education (blogs and wikis)	3 or 4
3 Visual learning	Models and visualization in chemistry education	5
4 Cloud initiation	*on all courses (e.g. Google Drive, Dropbox)*	
5 Collaboration	The central areas of chemistry education 1	6
6 Communication	Mathematics and science in society	3
7 Time management and productivity	Chemistry as a science and as a discipline	5
8 Digital citizenship	Introduction to chemistry education	3 or 4
	Inquiry-based chemistry teaching II	5
	Media and multiliteracy in science and technology education	5
9 Search strategies	The central areas of chemistry education 1	6
	The central areas of chemistry education II	4
10 Content area (Teaching materials)	The central areas of chemistry education 1	6
11 Interactives	Inquiry-based chemistry teaching II	5
12 Digital images	Media and multiliteracy in science and technology education	5
13 Powerful presentations	Science club education: Theory part	2
	Science Club Education: Practice part	3
14 Professional learning networks	Chemistry as a science and as a discipline	5
	Mathematics and science in society	3
15 Differentiation	Differentiation in chemistry education	3
16 Evaluation and assessment	The central areas of chemistry education 1	6
17 Dig the data	Inquiry-based chemistry teaching 1	5
18 Digital storytelling	Chemistry in the living environment	4
	The central areas of chemistry education 1	6
19 Blended or flipped classroom	Chemistry in the living environment	4
	Models and visualization in chemistry education	5
20 Emerging technologies	Inquiry-based chemistry teaching 1	5
	Media and multiliteracy in science and technology education	5

After being in use for one semester, the suitability of the ICT strategy for chemistry teacher education was examined by a case study The data was collected via pre- and post-semester e-questionnaires. The questionnaires were designed and piloted by the course teachers The questionnaires included both Likert-scales and open-ended questions about the subcategories integrated into the courses of the 2015 spring semester. The pre-questionnaire was completed by participants before the semester (N=40, answering percentage 80%) and the post-questionnaire at the end of the semester (N=32, answering percentage 73%) (Tuomisto, Aksela, & Jääskeläinen, 2015).

The aim of the ICT strategy inquiry was to find answers to the following questions: 1) How will chemistry teacher students' ICT skills change during ICT integrated teaching? 2) Which kind of ICT skills do students find to have a positive nature? 3) What kinds of challenges do students face when developing their ICT skills? (Tuomisto, Aksela, & Jääskeläinen, 2015).

At the beginning of the semester (pre-questionnaire), students had, on average, negligible knowledge or skills about simulation or modeling applications and the ways of virtually collaborating to share and modify materials. Students self-evaluated their skills as poor in blended or flipped classroom methods, in research strategies and in professional learning networks. But according to the pre-questionnaire results, students evaluated skills for critical evaluation of information (multi-literacy) and using digital learning platforms were good (Tuomisto, Aksela, & Jääskeläinen, 2015).

The most distinctive positive differences between the trainees' ICT skills before and after the ICT integrated courses could be seen in the areas of managing simulation applications and applying flipped classroom methods (Table 2). After the courses, the students evaluated their ICT skills once again and most remarked a difference in their ability to use learning platforms to search for teaching materials, but it was only a negligible difference. Skills for searching for research literature about chemistry education and in using modeling applications were evaluated as having developed to some extent, even though the skills related to the latter were evaluated as poor (mean 20). Students also remarked little improvement in their skills of working with digital applications (mean

15) and in professional learning network (mean 19) (Table 2) (Tuomisto, Aksela, & Jääskeläinen, 2015).

Table 2: Self-evaluation concerning the development of ICT skills among chemistry teacher students in ICT-integrated chemistry teacher education in the 2015 spring semester (Tuomisto, Aksela, & Jääskeläinen, 2015)

Self-evaluation concerning the development of ICT skills among chemistry teacher students in ICT-integrated chemistry teacher education in the 2015 spring semester	**Mean pre 0–5 (N=40)**	**Mean post 0–5 (N=32)**	**Skill development**
Simulation applications (e.g. PhET)	0.55	2.8	skills developed distinctively
Applications to support flipped classroom method	0.53	2.3	
Blogs (e.g. Wordpress, Blogger)	1.5	2.9	
Virtual sharing of ideas and materials (e.g. Lino)	0.48	1.8	
Searching research literature for chemistry education (e.g. ERIC, Google Scholar)	1.3	2.5	skills developed to some extent
Searching materials for teaching chemistry (e.g. LUMA.fi)	2.4	3.6	
Modeling applications (e.g. Jmol)	0.88	2.0	
Collaborative virtual working (e.g. Google Drive, Dropbox)	2.5	3.6	
Copyright and licenses (e.g. CC licenses)	1.9	2.9	
Citation software (esim. Citation Machine)	1.2	2.2	
Applications for managing your working (e.g. Evernote)	0.69	1.5	
Learning platforms (e.g. Moodle, Edmodo)	3.5	4.1	skills developed poorly
Professional learning networks (e.g. science blogs, Linkedln)	1.4	1.9	
Critical evaluation of information published in internet	3.9	3.9	skills developed negligible

In a post-questionnaire (19/32 students), the students reported that the most pleasant ICT themes in the courses were as follows:

- learning to use different applications (e.g. Lino, Kahoot!, modeling applications, PhET simulations)
- blogs (possibility to reflect on one's own learning; Wordpress, BlogSpot, Weebly)
- searching for research literature on chemistry education (about certain chemical phenomena; Google Scholar, NELLI, ERIC)
- making videos (e.g. iMovie)
- learning about copyright and applying it in course tasks (Tuomisto, Aksela, & Jääskeläinen, 2015).

The results reflect and support previous research findings that ICT-integrated chemistry teacher education seems to enhance participants' multifaceted ICT skills (Goktas et al, 2009). Students evaluated their skills as very good in using classroom management systems and collaborating on resources as well as in searching for suitable e-material for teaching. Both simulation applications for teaching chemistry concepts and phenomena and relevant resources for sharing materials and ideas have been acquired on the courses. According to previous research, subject-specific ways of using ICT are important for developing students' TCK (Goktas et al, 2009; Chai et al, 2011). In this study, students learned how to search relevant research literature about chemistry education, virtually share it with others and process their own learning in blog posts. This kind of new knowledge will possibly help to increase students' PK and PCK. Ertmer et al (2006) argue that students' attitudes towards ICT should be made positive during these courses, a goal which, according to this research, can be achieved by ICT-integrated education.

Based on the case study and earlier research, this ICT strategy has been further developed, with an even more intense focus on promoting ICT skills and knowledge to better meet the ICT skills requirements of future teachers. In the new strategy, the previous 20 subcategories have been replaced by three major themes: *pedagogical ICT skills, collaboration* and *digital citizenship.* All three of these themes will be implemented into every course given by the Chemistry Teacher Education Unit. Furthermore, the concept of TPCK, and the barriers to and enablers of

ICT-integrated teaching will be taught to all the students at the beginning of their studies. In addition, during every course the pre-service teachers will face real-school environments and opportunities to use ICT in a pedagogical way. In the future, the updated ICT strategy will also cover the in-service teacher training offered by the Chemistry Teacher Education Unit.

Molecular modelling through ICT in science education

An exemplary case of how multiple actors can and should cooperate in the LUMA ecosystem in order to enhance the use of ICT is the development of molecular modelling tools for chemistry teaching.

Models, modeling and visualizations are central in chemistry, as they make abstract entities visible, provide explanations and simplifications of complex phenomena (see figure 2), and illustrate predictions on molecules and reactions (Gilbert, Justi & Aksela, 2003). For these reasons, models and visualizations have also been a persistent topic of interest in the Chemistry Teacher Education Unit. In 2002, this interest led to the creation of a course dedicated to modeling and visualization, meant for pre-service chemistry teachers. The first courses introduced pre-service teachers to niche computational tools, available mainly only to scientists. As the years went by, the modeling tools became technically much simpler to use

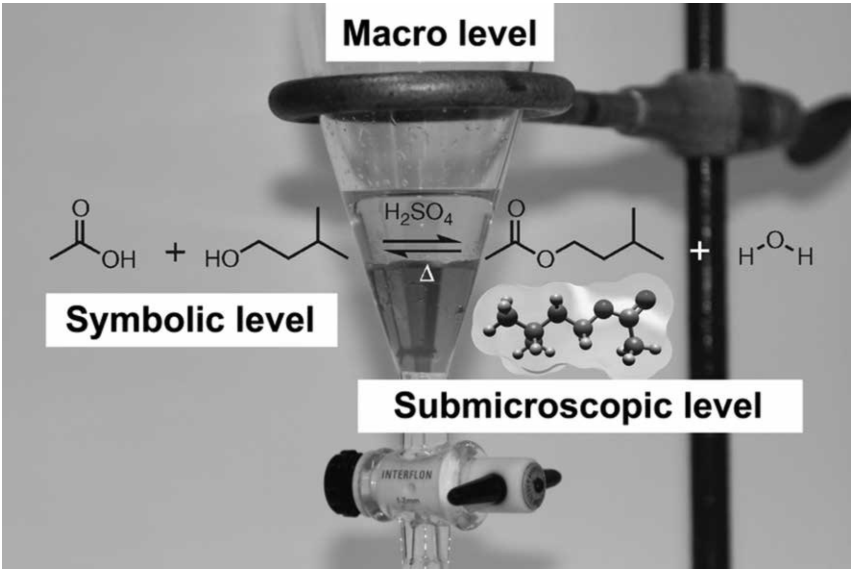

Figure 2: Students often find chemistry difficult to learn because of its three-dimensional nature. Chemical phenomena can be represented at three different levels: macro (observable), symbolic (H_2O) and sub-microscopic (electron flow) (Gabel, 1999). ICT offers essential tools for visualizing complex and abstract phenomenon.

In line with the relevant technological developments, the course aimed to develop the pedagogical use of these tools. To meet the needs of future teachers, a design-based research method was utilized. Here, the experiences and perceptions of the teachers involved in the LUMA ecosystem were investigated to discern what is important for pre-service teachers. The results suggested that molecular modelling could i) help students and teachers alike to examine chemical phenomena and the chemical structural information involved, especially the 3D-structure (Aksela & Lundell, 2007); and ii) develop students' visualization skills and illustrate models of difficult concepts (Aksela & Lundell, 2008). The Finnish chemistry teachers suggested the purposeful areas for modeling and visualization in chemistry to be orbitals, chemical bonding and spectroscopy (Aksela & Lundell, 2007).

The teachers' experiences proved to be crucial to the design process. It was discovered that in addition to technological support, the teachers wanted more pedagogical support in their utilization of the technology

(Aksela & Lundell, 2008). For example, teachers not only remarked that personal experiences help them to understand the value of ICT, but also that they want more adaptable materials in their native language (Aksela & Lundell, 2008) and that concept mapping activities are effective in web-based learning environments (Pernaa & Aksela, 2008). Furthermore, teachers wanted explicit examples of how certain curriculum aspects can be illustrated with molecular modeling (Aksela, Lundell & Pernaa, 2008). To address these needs, the teachers-in-training were included in the design-process of a new set of web-based activities that use a selection of ICT tools for both themselves and in-service teachers. Simultaneously, the feedback of the in-service teachers could help to further develop the actual activities and their practical implementation (Pernaa & Aksela, 2009).

The gathered results and a design-based research method were applied to the course design itself (Pernaa, Aksela & Västinsalo, 2010) and to the in-service training programs provided for teachers. Two important aspects of these training programs include the informal communication during workshops, where teachers share their ICT-related experiences, and the fact that if ICT is used to mediate communication, as in newsgroups or social media, there must be a way to stimulate intrinsic motivation (Juuti, Lavonen, Aksela, & Meisalo, 2009).

The next step is to further improve the student-centeredness of modeling activities, starting with the modeling course for future teachers. As of September 2015, the design-goal has been to support the personalization of the research-based knowledge constructed in the previous years. Currently, new solutions are also studied through a pilot scheme which is based on a blog-learning diaries approach with a peer feedback system.

Microcomputer-based laboratories as tools to support meaningful science learning

Another long-term process which seeks to enhance the use of ICT in chemistry learning within the LUMA ecosystem is the development of microcomputer-based laboratories, or MBLs. MBLs have been used for data acquisition, display and analysis to enhance experiments since the 1980s (Aksela, 2005). The displays visualize the progress of the phenomena in real-time, e.g. as a graph, which creates a direct link between the physical phenomena and its scientific representation which is suggested to i) motivate students (Nachmias, 1989); ii) off-load some of the cognition to the tools; iii) save time and promote discussion about the phenomena (Nakhleh, 1994; Rogers, 1996); and iv) increase understanding of the phenomena (Tinker, 1996; Aksela, 2005). Another feature that stimulates discussion is that the MBLs allow students to easily repeat the experiments using the same screen image and, thus, offers the possibility to easily compare and contrast their results (Newton 1997; Lavonen, Aksela, Juuti, & Meisalo, 2003). Other benefits include but are not limited to the ability to take the research of chemical phenomena outdoors (Lavonen et al, 2003).

However, reaping these supposed benefits is not easy: during the hands-on activities, many students talk about their graphs in a descriptive manner and much of their vocabulary is unscientific (Newton, 1997; Aksela, 2005). This emphasizes the role of teacher in the overall interaction and the importance of a learning environment that is carefully designed in order to maximize the potential benefits of MBLs (Aksela, 2005).

Long-term teacher training programs are needed to support the implementation of technology-based-inquiry (Gerard, Varma, Corliss, & Linn, 2011). The LUMA Centre Finland offers a visiting lab for student groups that adopts the aforementioned observations in their teaching and learning practices. In the visiting lab, pre-service chemistry teachers learn MBL implementation as a part of two courses focused on inquiry. The experiences obtained from the lab proved crucial in a COMBLAB project, in which research-based MBL activities were developed in a collaborative design process between six European universities. The aim of the activities was to enhance students' abilities to design their own experiments, interpret results and communicate findings.

The activities were published on a project website (http://wwwcomblabeu/ en) as material for European in-service teachers The project also boosted the short-term training programs provided in the LUMA ecosystem for in-service teachers. Additionally, one of the objectives of the COMBLAB project was to promote teachers' learning by using curriculum material design heuristics (Davis, & Krajcik, 2005) together with additional heuristics for technological skills to design curriculum material that supports teachers in using MBL-based inquiry materials (Tolvanen et al, 2014).

The results of this project shed some light on how students perceived the MBL activities; they suggested that most of the students understood the point of these activities, that the activities helped them learn and, most importantly, that the activities couldn't be done without the MBLs (Tortosa et al, 2014). It was also found that to promote learning, pre-service teachers still need support in the use of MBLs (Tolvanen, Aksela, Guitart, & Urban-Woldron, 2014). Further study related to the project focuses on the question of how MBLs can support understanding by identifying the characteristics which enable authoritative and dialogic discussion (Tortosa et al, 2014).

Virtual science learning environments for children and youths

This section summarizes the research-based virtual learning environments used in Finnish science education in the LUMA Centre Finland, and, as a unique example, the popular children's virtual science club (Vartiainen, & Aksela, 2016).

Virtual learning environments within the LUMA ecosystem

Most LUMA activities for children and youths are extra-curricular ICT is utilized as much as possible in the LUMA activities for children and youths as ICT is a natural part of 21st century life in developed countries. The use of ICT has the added benefit of interesting and motivating child and youth learners (e.g. Vihma & Aksela, 2014; Passey, Rogers, Machell, & McHugh, 2004). The use of ICT also promotes interaction and collaboration in multiple ways as well as encouraging personalized learning without the constraints of place and time. For these reasons, the LUMA Centre Finland uses more and more virtual learning environments to meet its goals of boosting interest and fostering learning.

The LUMA Centre Finland publishes freely available interactive web magazines, or webzines, with the aim of inspiring and supporting children and youths (e.g. Vihma & Aksela, 2014). The goal of these webzines is to encourage children and youth to interact with one another and with editorial teams made up of content experts at universities, companies, and so on. In this case, ICT provides a virtual environment for interaction and learning. Readers are encouraged to participate in discussions related to the articles, ask questions through ask-and-answer services, share their own ideas, experiences, and practices in the form of text, photos, or videos, and post the published content on social media sites.

An international MOOC course for youths as well as for teachers on the theme of sustainable energy was developed and is being run from 2015–2016 Studies on the participants' reasons for attending the MOOC are already underway (cf. Stuckey, Hofstein, Mamlok-Naaman, & Eilks, 2013).

Children's virtual science club

As a more detailed example of the virtual learning environments within the LUMA ecosystem, we intend to discuss the virtual science club (see figure 3), meant for 3–6-year-old children as well as for their parents or educators. The virtual science club was developed through design-based research (Vartiainen & Aksela, 2016).

Figure 3: A child experiments with colors at home following the instructions of the Virtual Science Club on a tablet.

Children show their interest in scientific phenomena they encounter in their everyday lives by constantly observing and asking questions. Previous research has shown that children under the age of eight are especially interested in phenomena related to physical sciences (Baram-Tsabari, Sethi, Bry, & Yarden, 2006), such as weather, phase changes of water, light, density and surface tension. Therefore, providing young children with a platform to explore and find answers to their questions is very relevant for this age group (Tolppanen, Vartiainen, Ikävalko, & Aksela, 2015). However, parents' attitudes towards science play an important role in the development of their children's future attitudes (Jeynes 2005, Alexander, Johnson, & Kelley, 2012). The origins of children's interest in science can be traced to early interactions in the context of science with their parents (Maltese & Tai, 2010). Though parents play a key role in a child's interest in science, there have only been a few attempts to bring science to homes. One reason for this may be parents' lack of knowledge about science (Shymansky, Yore, & Hand et al, 2000). Even kindergarten teachers often ignore science education, or they concentrate mostly on biological contexts (Tu, 2006). Therefore, there is a growing need to provide non-formal learning materials for young children that can be used at home.

In order to offer such materials, the LUMA Centre Finland provides the virtual science club for children, which was developed through design-based research. The cornerstones of the development process were playful learning (Bulunuz, 2013), the importance of social and cultural interactions (Vygotsky, 1978) and guided inquiry (Samarapungavan Patrick, & Mantzicopoulos, 2011; Brown & Campione, 1994). Furthermore, it was acknowledged that the child's developmental stage needs to be taken into consideration (Inhelder & Piaget, 1964). Therefore, the aim of the design-based research was to develop a learning environment that would:

- Be independent of time and place
- Support small children's learning of science process skills
- Encourage the whole family to be curious and conduct experiments together
- Be interactive
- Not require reading and writing skills
- Be playful

The club was created using these principles, as explained below. In order to overcome the fact that families are often busy, and parents may find it challenging to take their children to a physical science club, the clubs are organized online.

In the online club, instructional videos on how to conduct a scientific experiment are uploaded once a week. These videos can be watched at convenient times for the family or the kindergarten teacher. In the videos, motivational characters use stories and pictures to explain phenomena to be studied by the children. The characters provide information on the tools and materials needed to study a certain phenomenon as well as instructions on how to report on the experiment. However, the results of the experiment are not given. In fact, the tasks are open ended, meaning that children are free to choose their own experimental design. This also means that the children will end up with different results, which can be equally correct. In other words, children are not meant to replicate the experiment demonstrated by the motivational characters but rather to rehearse their own science process skills.

After watching the instructional video, children conduct the experiment and report on it with the help of their parents or kindergarten teacher. As the children may not be able to read or write yet, the reporting is usually done through photos or videos. In order to increase interaction between the clubbers from different parts of the country, their photos and videos are published on the club website, so that clubbers can view each other's work. The organizers of the club also give general video-feedback on the reports done by the children.

Our initial results indicate that the clubs can be highly successful learning environments for children and families if parents are given support in three different areas. Our study on using virtual science clubs at home was conducted as a case study. Seven parents who participated in the club with a child or children were interviewed via phone. Semi-structured narrative interviews were used with a stimulated recall method The data was analyzed qualitatively as a grounded theory.

As a result, a model was formed that explains the kind of support parents need to do science activities with their children at homes. The three dimensions that emerged from the study are: 1) the affective factor, 2) the knowledge and skills factor, and 3) the organizational factor. Parents' interest must be addressed to keep them engaged. For some parents, seeing how excited their children were to experiment was not enough of a motivation; they needed a more personal motivation. Parents also needed support to understand the scientific phenomena themselves, how to explain it to a small child and how to help their child find answers. Parents needed an external organizing body that would provide a schedule for experiments, send reminders, and give feedback.

As a main conclusion, we need to consider that there are in fact two learners a parent and a child with different support needs. Parents usually start science programs with great enthusiasm but give up quickly (Shymansky, et al, 2000). A virtual learning environment can offer a zone of proximal development for parents that can provide more personalized support than, for example, science packages that are sent home from school or day-care. If the virtual learning environments offered parents support in all of the aforementioned three dimensions, the parents would be more likely to continue non-formal science learning with their children. In the future, special support for parents will be developed on the basis of these results.

Design-based research as a tool for developing innovative ICT learning environments

Using ICT in education in a meaningful way often requires a systematic and careful learning environment design. This can be achieved using design-based research (DBR) as a design tool DBR is a research strategy in which experience-based design is supported through the combination of theoretical and experimental research phases (Edelson, 2002). It can be defined as a design methodology, which aims to develop teaching in real-world situations through a systematic, flexible and iterative research approach. The design process is carried out in iterative design cycles and the design decisions are justified through theory, formative and summative evaluation, collaboration between designers and the expertise of various stakeholders who form the design community (Design-Based Research Collective, 2003). The actual research methods used in DBR are determined on a case-by-case basis, as they depend on the design goals and design context (Barab, & Squire, 2004).

In every piece of DBR, the context and situation are unique, and careful planning and execution are necessary. As a result, it is difficult to present one comprehensive model for executing DBR projects, but this can be mitigated by Edelson's (2002) practical DBR framework. Edelson proposes that DBR can be controlled by examining the design decisions made during the research. Edelson divides the possible outcomes of DBR into three design decision categories:

1 The **design process** decision category addresses the possibilities and challenges related to the entire design process. The design process category explains how the design community achieved the designed outcome.
2 The **problem analysis** decision category discusses the possibilities and challenges related to domain-specific knowledge. This category enables designers to determine the objectives of the design solution.
3 The **design solution** decision category addresses the possibilities and challenges of the design solution (a concrete artefact). This category produces, for example, new knowledge of the technical aspects and possible ways of using the designed learning environment (Edelson, 2002).

DBR is a relatively young research method in the educational field. It was developed in the 1990s to bridge the gap between educational research and the pragmatic needs of the actual educational field in schools and businesses. Teachers have long criticized the educational research community for not providing them with useful information (Brown, 1992). Over the past 20 years, the DBR community has been using DBR as a design strategy and developing DBR itself as a method. The use of the DBR has been steadily growing, and nowadays it is a widely used and published educational research tool (Anderson, & Shattuck, 2012).

DBR is well suited for developing ICT-based learning environments because it is a very practical approach DBR typically produces concrete learning environment artefacts that have been developed in collaboration with end-users, such as teachers and students. In addition, Edelson's model offers designers various possibilities to learn from the design work, and at the same time, the research-based approach produces new knowledge for science (Edelson, 2002; Pernaa & Aksela, 2013).

In the Finnish LUMA ecosystem, practically all research-based learning environment design work has been carried out via DBR since 2005. It has been used for developing inquiry-based MBL learning environments (Aksela, 2005), courses for teachers (Pernaa, Aksela & Västinsalo, 2010), software (Pernaa & Aksela, 2013) and virtual science clubs (Vartiainen, & Aksela, 2015), to name just a few examples.

Conclusions

For the past decade, the LUMA Centre Finland has implemented and developed ICT education for pre-service and in-service science teachers as well as for learners of different age groups (e.g. families). This has been done through research-based ICT activities, pedagogical models and virtual learning environments (e.g. virtual clubs, webzines, and webinars). Over the years, the implemented models have been continuously developed using design-research, increasing the reliability and the validity of the models used. As this paper shows, the implemented ICT activities have provided students with positive learning experiences and have helped to advance their learning by involving them in phenomena-based, contextual, and relevant learning environments.

Regarding pre-service and in-service teacher training, both subject specific and integrated ICT training have been found to be useful (e.g. Helppolainen & Aksela, 2015; Tuomisto, Aksela, & Jääskeläinen, 2015). Molecular modelling and microcomputer-based learning environments in particular have proven to be useful tools for meaningful chemistry teaching at schools and in teacher training. Furthermore, models, modelling and visualizations play a central role in chemistry as they make abstract entities visible. Having ICT instruction that is integrated into all pre-service teacher training courses (rather than separate ICT courses) positively impacts teachers' use of ICT (Moursund, & Bielefeldt, 1999; Tuomisto, Aksela, & Jääskeläinen, 2015).

However, this paper also points out that there is still work to be done in implementing ICT in science education. As teachers play a key role in how ICT is implemented in classroom practice, further teacher training is needed. In such training, technological pedagogical content knowledge (TPCK) should be provided, meaning that training does not only focus on technical support but also on pedagogical support in using technical tools. Furthermore, training should focus on subject specific ICT tools and the concrete needs of the teachers.

More research is needed to understand, in detail, what type of training best supports teachers' ability to adopt ICT not only at a technical level but also at a pedagogical one. In addition, further research is needed to understand what type of pedagogical models best support the development of children's and youths' ICT skills in mathematics and best enrich science and technology education and teacher training (e.g. MOOCs).

References

Aksela, M (2005) *Supporting meaningful chemistry learning and higher-order thinking through computer-assisted inquiry: A design research approach* (Doctoral dissertation) Retrieved from https://heldahelsinkifi/handle/10138/21127

Aksela, M (2010) Evidence-Based Teacher Education: Becoming A Lifelong Research-Oriented Chemistry Teacher *Chemistry Education Research and Practice*, 11, 84–91

Aksela, M & Juvonen, R (1999) *Kemian opetus tänään* [*Chemistry Education Today*] Opetushallitus Helsinki: Edita Oy

Aksela, M, & Karjalainen, V (2008) *Kemian opetus tänään: Nykytila ja haasteet Suomessa* (Chemistry Education Today In Finland] University of Finland,
Center of Chemistry Education Helsinki: Yliopistopaino

Aksela, M, & Lundell, J (2007) Kemian opettajien kokemuksia tietokoneavusteisesta molekyylimallinnuksesta In M Aksela, & M Montonen (Eds), *Uusia lähestymistapoja kemian opetukseen perusopetuksesta korkeakouluihin*, (pp 226–247) Helsinki: Yliopistopaino

Aksela, M, & Lundell, J (2008) Computer-based molecular modelling: Finnish school teachers' experiences and views *Chemistry Education Research and Practice*, 9, 301–308

Aksela, M Lundell, J & Pernaa, J (2008) Molekyylimallinnuksen mentoreita kemian opetuksen ja oppimisen tueksi In J Välisaari & J Lundell (Eds), Kemian opetuksen päivät 2008: *Uusia oppimisympäristöjä ja ongelmalähtöistä opetusta*, (pp 59–68) Helsinki: Yliopistopaino

Alexander, J M, Johnson, K E, & Kelley, K (2012) Longitudinal analysis of the relations between opportunities to learn about science and the development of interests related to science *Science Education, 96* (5), 763–786 doi:101002/ sce21018

Anderson, T, & Shattuck, J, (2012) Design-Based Research A Decade of Progress in Education Research *Educational Researcher,* 41(1), 16–25 doi:103102/0013189X11428813

Angeli, C, & Valanides, N (2009) Epistemological and methodological issues for the conceptualization development, and assessment of ICT-TPACK: advances in technological pedagogical content knowledge (TPACK) *Computers & Education*, 52(1), 154–188

Barab, S, & Squire, K (2004) Design-based research: Putting a stake in the ground *The Journal of the Learning Sciences*, 13(1), 1–14

Baram-Tsabari, A, Sethi, R J, Bry, L, & Yarden, A (2006) Using questions sent to an Ask-A Scientist site to identify children's interests in science *Science Education, 90*(6), 1050–1072

Brown, A (1992) Design Experiments: Theoretical and Methodological Challenges in Creating Complex Interventions in Classroom Settings *The Journal of Learning Sciences,* 2 (2), 141–78

Brown, A L, & Campione, J C (1994) *Guided discovery in a community of learners.* The MIT Press

Bulunuz, M (2013) Teaching science through play in kindergarten: Does integrated play and science instruction build understanding? *European Early*
Childhood Education Research Journal, 21(2), 226–249

Chai, C S, Koh, J L K, Tsai, C-C, & Tan, L L (2011) Modeling primary school pre-service teachers' Technological Pedagogical Content Knowledge (TPACK) for meaningful learning with information and communication technology (ICT) *Computers and Education*, 57, 1184–1193

Design-based Research Collective (2003) Design-based research: An emerging paradigm for educational inquiry *Educational Researcher*, 32(1), 5–8

Davis, E A, & Krajcik, J S (2005) Designing Educative Curriculum Materials to Promote Teacher Learning *Educational Researcher*, 34(3), 3–14

Edelson, D C (2002) Design research: What we learn when we engage in design *The Journal of the Learning Sciences*, 11, 105–121

Ertmer, P A (1999) Addressing first- and second-order barriers to change: Strategies for technology integration *Educational Technology Research and Development*, 47(4), 47–61

Ertmer, P A, Ottenbreit-Leftwich, A, & York, C S (2006) Exemplary technology-using teachers: Perceptions of factors influencing success *Journal of Computing in Teacher Education*, 23(2), 55–61

Gabel, D (1999) Improving Teaching and Learning through Chemistry Education Research: A Look to the Future *Journal of Chemical Education*, *76*(4), 548

Gilbert, J, Justi, R, & Aksela M K (2003) The visualization of models: A metacognitive competence in the learning of chemistry *Proceedings of 4th International Conference of the European Science Education Research Association (ESERA)* Noordwijkerhout, Netherlands

Gerard, L F, Varma, K, Corliss, S B, & Linn, M C (2011) Professional development for technology-enhanced inquiry science *Review of Educational Research*, 81, 408–448

Goktas, Y, Yildirim, S, & Yildirim, Z (2009) Main barriers and possible enablers of ICTs integration into pre-service teacher education programs *Educational Technology & Society*, 12(1), 193–204

Helppolainen, S, & Aksela, M (2015) Science teachers' ICT use from a viewpoint of Technological Pedagogical Content Knowledge (TPCK) *LUMAT, 3*(6), 783–799

Inhelder, B, & Piaget, J (1964) The growth of logical thinking from childhood to adolescence New York, NY: Basic Books

Jeynes, W H (2005) A meta-analysis of the relation of parental involvement to urban elementary school student academic achievement *Urban Education, 40*(3), 237–269

Juuti, K, Lavonen, J, Aksela, M, & Meisalo, V (2009) Adoption of ICT in science education: a case study of communication channels in a teachers' professional development project *Eurasia Journal of Mathematics, Science & Technology Education*, *5*(2), 103–118

Koehler, M J, & Mishra, P (2008) Introducing TCPK Teoksessa AACTE Committee on Innovation and Technology (Eds), *Handbook of Technological Pedagogical Content Knowledge (TPCK) for Educators* (pp 3–29) Routledge: Oxon

Koehler, M J, & Mishra, P (2009) What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education*, *9*(1), 60–70

Koehler, M J, & Mishra, P, & Yahya, K (2007) Tracing the development of teacher knowledge in a design seminar: integrating content, pedagogy, and technology *Computers & Education*, 49(3), 740–762

Lavonen, J, Aksela, M, Juuti, K, & Meisalo, V (2003) Designing user-friendly datalogging for chemical education through factor analysis of teacher evaluations *International Journal of Science Education*, 25(12), 1471–1487

Lavonen, J, Juuti, K, Aksela, M, & Meisalo, V (2006) A professional development project for improving the use of information and communication technologies in science teaching *Technology, Pedagogy and Education*, 15(2), 159–174

Maltese, A V, & Tai, R H (2010) Eyeballs in the fridge: Sources of early interest in science *International Journal of Science Education, 32*(5), 669–685

Meisalo, V, Lavonen, J, & Sormunen, K, (2011) ICT in Finnish Initial Teacher Education Country Report for the OECD/CERI New Millennium Learners Project ICT in Initial Teacher Training *Reports of the Ministry of Education and Culture* 2010:25 Helsinki: Ministry of Education

Mishra, P, & Koehler, M J (2006) Technological pedagogical content knowledge: A framework for teacher knowledge *Teachers Colle.g.e Record*, 108(6), 1017–1054

Moursund, D, & Bielefeldt, T (1999) Will new teachers be prepared to teach in a digital age? *A national survey on information technology in teacher education.* International Society for Technology in Education Retrieved from http://files ericedgov/fulltext/ED428072pdf

Myllyviita, A, & Lavonen, J (2014) Tieto- ja viestintätekniikka opettajankoulutuksessa In A Rautiainen, M Räkköläinen, E Helin, P Pohjonen, & K Nyyssölä (Eds), *Opettajankoulutuksen tilannekatsaus: Tilannekatsaus marraskuu 2014* (116–125) Retrieved from http://wwwophfi/download/163626_ opettajankoulutuksen_tilannekatsauspdf

Nachmias, R (1989) The microcomputer based laboratory: Theory and practice *Me.g.amot Behavioural Science Quarterly,* 32, 245–261

Nakhleh, M B (1994) A review of microcomputer-based labs: How have they affected science learning? *Journal of Computers in Mathematics and Science Teaching*, 13(4), 368–381

Newton, L (1997) Graph talk: some observations and reflections on students' data-logging *School Science Review*, 79(287), 49–53

Opetushallitus (2014) *Perusopetuksen opetussuunnitelman perusteet 2014 Määräykset ja ohjeet* 2014:96 Retrieved from http://wwwophfi/download/163777_perusopetuksen_opetussuunnitelman_perusteet_2014pdf

Opetushallitus (2015) *Lukion opetussuunnitelman perusteet 2015* Retrieved from http://wwwophfi/saadokset_ja_ohjeet/opetussuunnitelmien_ja_tutkintojen_perusteet/lukiokoulutus/lops2016/103/0/lukion_opetussuunnitelman_perusteet_2015

Passey, D, Rogers, C, Machell, J, & McHugh, G (2004) The motivational effect of ICT on pupils Nottingham: University of Lancaster

Pernaa, J, & Aksela, M (2008) Concept maps as meaningful learning tools in a web-based chemistry material *Concept Mapping: Connecting Educators. Tallinn, Estonia & Helsinki, Finland*

Pernaa, J, & Aksela, M (2009) Chemistry teachers' and students' perceptions of practical work through different ICT learning environments *Problems of Education in the 21st Century*, *16*, 80–88

Pernaa, J (2011) *Kehittämistutkimus: Tieto- ja viestintätekniikkaa kemian opetukseen* (Doctoral dissertation) Retrieved from https://heldahelsinkifi/handle/10138/28007

Pernaa, J, & Aksela, M K (2013) Model-based design research: A practical method for educational innovations *Advances in Business-Related Scientific Research Journal*, 4(1), 71–83

Pernaa, J, Aksela, M, & Västinsalo, J (2010) Kemian mallit ja visualisointi -kurssin yhteisöllinen uudistaminen malliteoriaan pohjautuvalla kehittämistutkimuksella In M Aksela, J Pernaa & M Rukajärvi-Saarela (Eds), *Tutkiva lähestymistapa kemian opetukseen*, (pp 96–114) Retrieved from http://www helsinkifi/kemma/data/kop-2010pdf

Rogers, L T (1996) A Study of Pupil's Skills of Graphical Interpretation with Reference to the Use of Data-Logging Techniques in Microcomputer-Based Labs: Educational Research and Standards *NATO ASI Series F: Computer and Systems Sciences*, 156, 165–176

Rogers, L, & Twidle, J (2013) A pedagogical framework for developing science teachers with ICT R*esearch in Science & Technological Education*, 31(3), 227–251

Samarapungavan, A, Patrick, H, & Mantzicopoulos, P (2011) What kindergarten students learn in inquiry-based science classrooms *Cognition and Instruction, 29*(4), 416–470

Shymansky, J A, Yore, L D, & Hand, B M (2000) Empowering families in Hands-on science programs *School Science and Mathematics, 100*(1), 48–58 Stuckey, M, Hofstein, A, Mamlok-Naaman, R, & Eilks, I (2013) The meaning of "relevance" in science education and its implications for the science curriculum *Studies in Science Education, 49*(1), 1–34

Tinker, R F (Ed) (1996) Microcomputer-based labs: Educational research and standards Berlin: Springer

Tolppanen, S, Vartiainen, J, Ikävalko, V-M, & Aksela, M K (2015) Relevance of non-formal education in science education In I Eilks, A Hofstein (Eds), *Relevant Chemistry Education: From Theory to Practice. (p. 335–354). Rotterdam:* Sense Publishers

Tolvanen, S, Aksela, M, Guitart, F, & Urban-Woldron, H (2014) *Research based future science teacher training on using ICT-enhanced inquiry activities E-Book Proceedings of the ESERA 2013 Conference: Science Education Research For Evidence-based Teaching and Coherence in Learning. Retrieved from* http://wwweseraorg/media/esera2013/Simo_Tolvanen_16Dec2013pdf

Tortosa, M, Skorsepa, M, Guitart, F, Urban-Woldron, H, Aksela, M, Tolvanen, S,… & Smejkal, P (2014) Design of research-based lab sheets for acquisition of science competencies using ICT real-time experiments Do students get the point of what they are doing? *E-Book Proceedings of the ESERA 2013 Conference: Science Education Research For Evidence-based Teaching and Coherence in Learning.* Retrieved from http://wwweseraorg/media/esera2013/Montserrat_Tortosa_12_02_2014pdf

Tu, T (2006) Preschool science environment: What is available in a preschool classroom? *Early Childhood Education Journal, 33*(4), 245–251

Tuomisto, M, Aksela, M, & Jääskeläinen, M (2015) Osaavia ja ennakkoluulottomia kemian aineenopettajia tieto- ja viestintätekniikkaa monipuolisesti hyödyntämällä *LUMAT, 3*(6), 762–782

Vartiainen & Aksela (2015) Virtual Science Club for families Published in the webpages of the LUMA Centre Finland It will be published as an article later on

Vihma, L, & Aksela, M (2014) Inspiration, Joy, and Support of STEM for Children, Youth, and Teachers through the Innovative LUMA Collaboration In H Niemi, J Multisilta, L Lipponen, & M Vivitsou (Eds), *Finnish Innovations and Technologies in Schools: A Guide towards New Ecosystems of Learning.* (pp 129–144) Rotterdam: Sense Publishers

Vygotsky, L (1978) Interaction between learning and development *Readings on the Development of Children, 23*(3), 34–41