Four Stages of Research on the Educational Use of Ubiquitous Computing

Jari Laru, Piia Näykki, and Sanna Järvelä

Abstract—In this paper, the Gartner Group's hype cycle is used as the basis for categorizing and analyzing research on the educational use of ubiquitous computing. There are five phases of the hype cycle: the technology trigger, the peak of inflated expectations, the trough of disillusionment, the slope of enlightenment, and the plateau of productivity. Research on the educational use of mobile technology is divided in this paper into four stages: (i) a period of mobility and personal digital assistants (PDAs); (ii) the era of wireless internet learning devices; (iii) the introduction of social mobile media; and (iv) a ubiquitous future. In addition, three empirical case studies are used as examples of these developmental stages. These case studies demonstrate the diversity of contexts, methods, and technologies used, ranging from the workplace to nature trails, from inquiry learning to collaborative knowledge building, and from PocketPCs to smartphones. The four stages of educational use in the context of the hype cycle and the case studies together emphasize that pedagogically grounded instructional design is needed to put emergent technologies to effective use to promote learning skills, namely self-regulated learning and collaboration, and to prepare people for the 21st century learning society.

Index Terms—Education, mobile and personal devices, collaborative learning, social networking

1 Introduction

The strengthening role of smartphones, internet tablets, and other mobile devices in our everyday lives is an example of *ubiquitous computing*. The term was coined by Weiser [1], who wrote that "the most profound technologies are those that disappear [because t]hey weave themselves into the fabric of everyday life until they are indistinguishable from it". Weiser is widely considered the father of ubiquitous computing, an environment in which the computer is integral to and embedded in the background of daily life.

Although Weiser was the first to use the term "ubiquitous computing," others had explored this notion as early as two decades before him. As early as the 1970s, Alan Kay imagined a handheld, notebook-size computer for children, which he called the Dynabook [2], [3]. He thought that computers might be instruments that would support the construction of knowledge in a variety of media anytime and anywhere [3], [4]. At about the same time, Papert [5] predicted "a massive penetration of powerful computers into people's lives" and with it a paradigm change in teaching and learning. Papert called his approach to learning "constructionism," viewing it as a variant of constructivism [6]. Early efforts at the Xerox Parc laboratory supervised by Allan Kay led immediately to the development of personal computing and can be seen as an enduring success resulting from research on technology-enhanced learning. Instead, the development of mobile devices and applications at the level required to realize the visions of scientists in the early 1970s took until the late 90s, when the first handhelds and mobile communicators appeared in the U.S. and Europe [7].

In this paper, the Gartner Group's hype cycle (see Fig. 1) is used as a basis on which to categorize and analyze research on the educational use of ubiquitous computing because, as noted by Fenn [8], the hype cycle "characterizes the typical progression of an emerging technology." As depicted (see Fig. 1), the hype cycle has five stages: the technology trigger, the peak of inflated expectations, the trough of disillusionment, the slope of enlightenment, and the plateau of productivity. Because the technology is at different levels of development in each of the five phases of the cycle, research on the educational use of the technologies can be done in stages [9]. These stages are not linear in the strictest sense; rather, they follow the developmental steps of research in the field. In this case, the hype cycle is also used to structure an examination of the development of the general idea of mobile computer-supported learning. This is achieved by adding a layer of several megatrends in the technology-enhanced learning field on top of the hype cycle (shown at the top of Fig. 1).

In addition to an analysis of the general idea of mobile devices in education and an introduction to the four stages of the educational use of ubiquitous computing, three empirical case studies are included in this paper as examples of the developmental stages over a five-year period (in 2002, 2004, and 2007).

These case studies have been carried out by setting up iterative design experiments [10] in different learning settings during the first author's doctoral studies. The iterations were not explicit between the technologies used, but have tended more to the side of instructional design.

Three cases have served two purposes for the iterative development of instructional design: a) outcomes were used to guide revisions to the instructional design and practical arrangements themselves, but also informed the

- *The authors are with the Faculty of Education, Learning and Educational Technology Research Unit (LET), University of Oulu, 90014 Oulu, Finland. E-mail: {jari.laru, piia.naykki, sanna.jarvela}@oulu.fi.*

Manuscript received 15 Apr. 2014; revised 19 July 2014; accepted 14 Sept. 2014. Date of publication 1 Oct. 2014; date of current version 13 Mar. 2015.
For information on obtaining reprints of this article, please send e-mail to: reprints@ieee.org, and reference the Digital Object Identifier below.
Digital Object Identifier no. 10.1109/TLT.2014.2360862

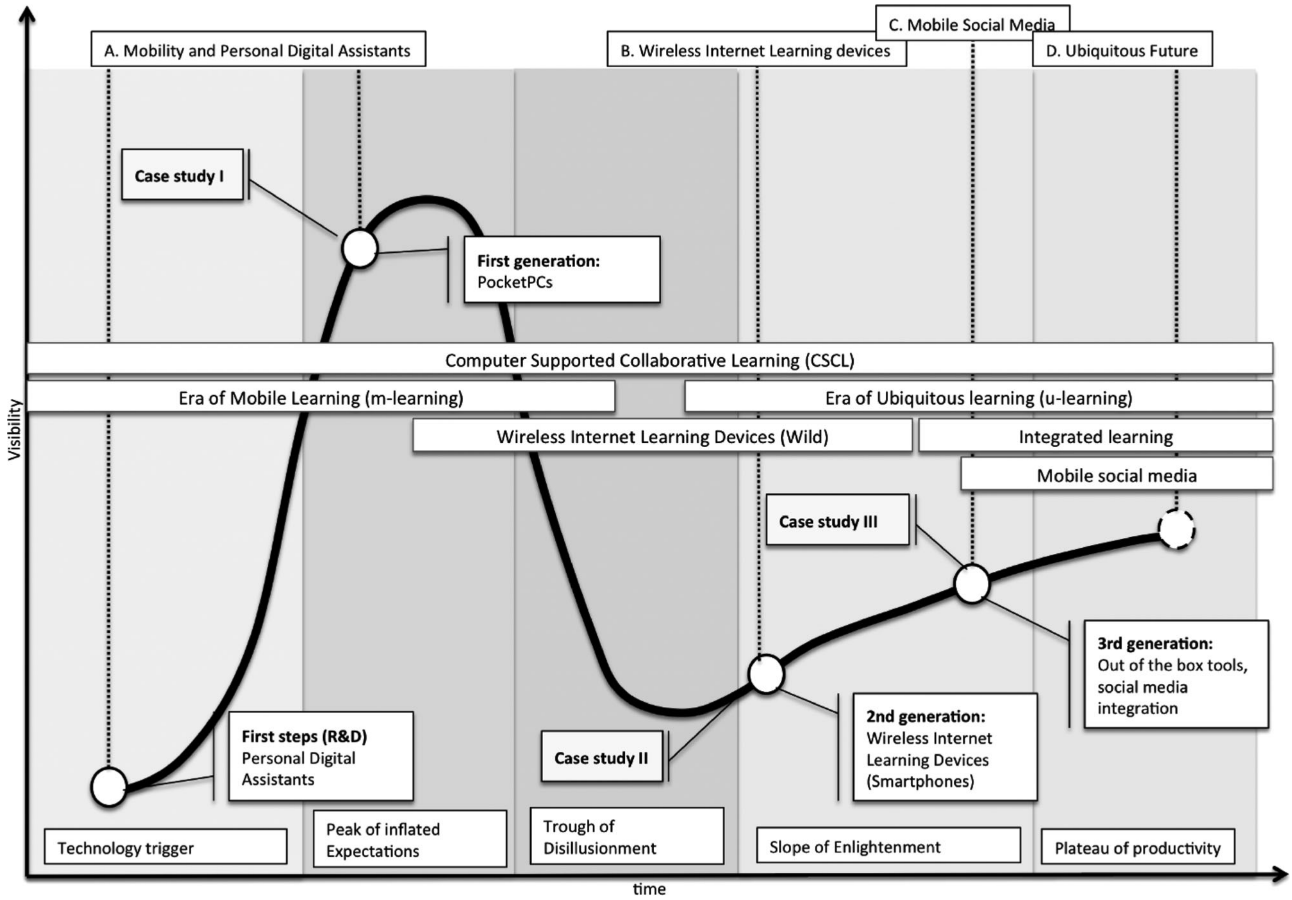

Fig. 1. Gartner's hype curve and the development of "mobile learning".

selection of mobile tools; and b) outcomes also served to help researchers to understand the learning processes and how these were affected by the tools, the instructional designs, and the arrangements themselves.

The hype cycle begins with the era of technology triggers, which were the product launches of the Apple Newton, the Palm Pilot, and the Nokia Communicator in the late 1990s, followed by Microsoft's PocketPC in the early 2000s. Later devices are considered first-generation gadgets in this cycle. These early developments in ubiquitous communication led to a peak of inflated expectations, when some scholars thought that mobile devices would revolutionize education [11], [12]. Typical for this period was the move to refer to the educational use of mobile devices using the terms "mobile learning" and "m-learning" [13], [14], [15]. This period is described in the following section.

In the third stage, that of disillusionment, critical accounts concerning technology determinism started to appear. For example, in an extensive review of the early mobile learning projects, Frohberg et al. [16] found that the "tool support of most projects is not pedagogically ambitious, [and only] a ... minority provide tools that aim at realizing higher pedagogical goals". At the same time that the first critical considerations started to emerge, seminal accounts of mobile computer-supported learning were also published, such as the idea of wireless internet learning devices (WILD) [17] and integrated learning [18]. These developments, together with new affordances of mobile technologies, led to the hype cycle stage of enlightenment. In this stage, some second-generation mobile devices (smartphones with 3G connectivity, for example) eased the research in the field. Two major phases emerged related to the development of wireless internet learning devices and mobile social media.

From the present perspective, this field of research is currently in the plateau of productivity phase. The world is entering the age of mobilism [19]. New technology tools fit more readily and naturally into our lives; increasingly wide-ranging, inexpensive, and easy-access-to-internet wireless devices, and a variety of web-based personal publishing and social software tools are making computing a truly ubiquitous and "continuous" part of our lives [20].

2 Four Eras in the Educational Use of Ubiquitous Computing

2.1 First Years of Research on the Educational Use of Ubiquitous Computing: Mobility and PDA(s)

The first years of research on the educational use of mobile technologies focused either on mobility and other contextual issues, such as spatial and temporal flexibility for workers [21], [22] or exploring the educational use of three distinct families of mobile devices: i) laptops [23], [24], [25], ii) personal digital assistants and a wave of devices that followed in this category (e.g., PocketPC and Palm Pilot) [26], [27], and iii) scientific calculators [28], [29]. In this paper, the emphasis is on handheld computers or handhelds (devices included in this definition are personal digital assistants, smartphones, tablet computers, (networked) graphing calculators, etc.), so laptop experiments are not further discussed.

A majority of the research conducted before 2002-2003 was done with PDAs, although some projects also explored the possibilities of the wireless application protocol and other emerging technologies [12]. One of the biggest explorative studies was a systematic evaluation of handheld technology in education—the palm education pioneer (PEP) program, which distributed classroom sets of handheld computers through a competitive grant process [30]. The goals of the project were to evaluate the effectiveness of the handheld computers in real-world settings and to aggregate the knowledge base for the participating teachers. In their initial grant proposals, teachers anticipated that the handhelds would engage students in personalized and self-directed learning activities. However, teachers reported increased collaboration and cooperation as a benefit of technology use in their classrooms [30], [31]. However, collaboration in the PEP program was limited to face-to-face situations mediated by handhelds due to limitations in connectivity (short-range infrared connectivity between handhelds).

In their literature review, Shin et al. [27] described three major educational uses for early handheld computers in K-12 education: i) researching, organizing, and expressing; ii) capturing and analyzing scientific data [32], [33]; and iii) limited communication and collaboration in their literature review of early research in the field. In their review, they found many curriculum- or teacher-related issues. A "teacher factor" emerged as a pattern that can be described as follows: "teachers in their first year of using a digital tool—be it handhelds, laptops, graphing calculators, and so on—will not use that technology particularly effectively at first." To conclude, their review revealed how the teacher-centered educational use of handhelds in the classrooms was at that time; however, several authors have argued that activity patterns remain similar today [7], [34].

New generations of early mobile devices have had incrementally better resolution screens, built-in cameras, expandable memory, and a variety of wireless capabilities that were not available for the early research in this field [27]. Suddenly, of particular note were the increasing educational affordances and converging functionalities of contemporary mobile devices, both PDAs and smartphones, moving them from the markets of basic telephony and electronic diaries to that of small laptops [35]. However, early smartphones, PocketPCs, and other networked handheld devices were marked by various usability and technological issues [36], [37] and can therefore be called the first generation of "mobile learning" tools.

The idea of mobile learning was presented by Sharples [38] in terms of technological developments; according to him, new technological affordances enabled a "new genre of educational technology—personal (handheld or wearable) computer systems that support learning from any location throughout a lifetime." The various educational affordances of wireless technologies suggested by researchers [17], [39] have paved the way for the emergence of so-called mobile learning or ubiquitous learning initiatives, such as G1:1 learning [40]. While some

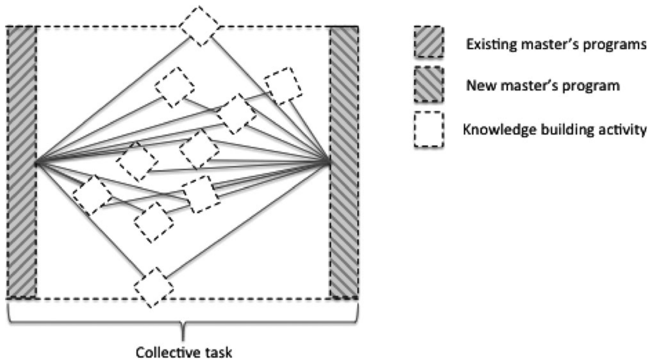

Fig. 2. Instructional design of the first case study.

researchers elaborate terms deeply in scientific practices, mobile devices and wireless networking technologies in education are still understood by many as "an extension of e-learning" [14], [41] or a mainstream, pervasive learning delivery medium [11]. However, these simplistic views ignore the fact that modern education and pedagogy highly value active, productive, creative, and collaborative learning methods, far beyond the absorption of codified information [42].

The advent of modern smartphones and tablets in the early 2000s was the second wave of pioneering projects. For this set of projects, the focus was switched from explorative initiatives for identifying the benefits and constraints of using handheld computers to supporting learning activities. Four different trends can be distinguished: i) augmented learning experiences, in which mobile devices are used to create situated educational location-based games [43], [44], [45], [46], [47]; ii) classroom response systems [48], [49], [50]; iii) teaching and learning support systems and organizers [51], [52]; and iv) tools supporting collaborative activities among students for individual, small-group, and whole-class learning [17], [53], [54], [55]. The next three case studies will be explicated to illustrate the developments in the educational use of ubiquitous computing.

2.1.1 CASE Study 1: Designing a New Virtual Master's Program in the Context of a Distance Education Network

This study was conducted in naturalistic settings at the University Learning Center. The center offers distance education on information processing sciences through several retraining programs at seven independent regional learning centers. The volunteer participants ($N = 10$) were split into three teams at two different locations in a northern area of Finland. The participants (nine men and one woman) comprised four project managers, a lecturer, a computer specialist, an educational designer, and three new media designers. All participants had previous experience working together in the same distributed organization.

In this case study [56], the participants shared a major problem, which was an assignment to design a new distance education master's program in a new domain (see Fig. 2). The instructional design in this first case study was simplified: a knowledge-building tool was just embedded into existing practices. To design the program, participants were offered a mobilized version of collaborative technology

Fig. 3. FLE3mobile.

(FLE3mobile) with a dialogue model of knowledge building at their disposal. Ideas of knowledge building and progressive inquiry learning [57] were operationalized in sentence openers. At the pedagogical level, participants were free to collaborate as they desired while designing the program.

2.1.2 Case Study 1: Technology Used in the Case Study

Each participant was provided with a Hewlett-Packard Jornada 586 handheld computer equipped with wireless internet connectivity. The tools used in the experiment consisted of FLE3mobile [56], an experimental mobile version of FLE3, and a proprietary software suite consisting of generic tools (Pocket Word, Pocket Excel, Pocket Internet Explorer, Pocket Outlook, MSN Messenger, Terminal Services Client, Note Taker, Voice Recorder, Calculator, and File Explorer). In practice, the mobile version of FLE3 was created by adapting the user interface to be compatible with html/CSS-level restrictions of the PocketIE (web browser for the PocketPC) (see Fig. 3).

FLE3[1] is designed to support group-centered work that concentrates on creating and developing expressions of knowledge. Knowledge creation takes place in a shared workspace where students carry out progressive discourse interaction and add their knowledge artifacts to the database [58], [59], [60].

The desktop version of FLE3 consists of three modules designed to facilitate collaborative knowledge building and collaborative design work: i) a virtual desktop module (webtop), ii) a knowledge-building module, and iii) a Jam session module. [59], [60]. In the mobile version of the FLE3 tool, only the webtop and knowledge-building modules were activated. Furthermore, the knowledge-building module was only functionality that was used in the actual experiment [61].

1. FLE3 was developed by the Learning Environments for Progressive Inquiry Research Team at the UIAH Media Lab, University of Art and Design Helsinki with the Center for Research on Network Learning and Knowledge, Department of Psychology, University of Helsinki.

To help in writing contributions, the knowledge building discussion was scaffolded and structured by knowledge types in the form of semi-structured sentence openers that label the thinking mode of each discussion note. In other words, FLE3 offers a semi-structured communication interface for participants where they were able to publish problem statements or questions and engage in a knowledge building dialogue around these problems by posting their messages to the common workspace according to predefined categories that structured the dialogue. The categories used in this study were question, own explanation, scientific explanation, summary, comment, and process comment [59].

2.1.3 Empirical Evidence from the Case Study

In general, the results revealed minimal interaction in the shared workspace (FLE3mobile). The social network analysis and interviews revealed that despite the involvement of some central participants, their network was sparsely knit, and it did not constitute a community of practice. In summary, being a sparsely knit network without the need for daily collaboration, they did not have a need for dense collaboration in the shared workspace [56].

In addition, based on the interviews participants had considerable difficulties with adopting mobile technologies and wireless networks. As handhelds were a new technology for all participants, they were compared at every point with corresponding technologies and with low-tech tools like pocket calendars, paper, and pencils. In 2002 participants were restricted to in-house or on-site areas with Wi-Fi coverage, of which was also acknowledged by subjects in the interviews [56].

Despite several issues, this case study was a serious attempt to solve the issue of which was highlighted by one of the subjects (project manager); they did not have a shared workspace, knowledge management systems or other collaboration tools to support their practices [56]. So the representative of the organization wanted to test how emerging technologies would support their daily practices.

The instructional design of the first case study was made in 2002, the same year as Dillenbourg published his pioneering attempt [18] to analyze collaborative scripts in which he identified a number of aspects that have served as a preliminary framework for script design and comparison for many scholars. In this light, non-participative behavior might have been avoided by designing activities as a sequence of timed spaces, each characterized by fine-tuned attributes, for example describing the nature of the task and group formation.

2.2 Appearance of the First Wireless Internet Learning Devices Together with Pedagogically Ambitious Learning Goals

More recently, research on the use of mobile technologies has contributed to the potential to support learners in studying a variety of subjects [62], [63] in elementary education [53], [64] as well as in higher education [54], [55], [65]. While the main focus of the research activities has been in developed countries, some of the projects have aimed to bridge the digital divide by "enabling people in developing world not only access information, but also contribute information back—thus becoming active participants in the information society" [66 p. 212], [67], [68].

A considerable amount of research in this decade has been driven by technological challenges, while few studies have dealt with questions of how meaningful and productive mobile technology-supported (collaborative) learning is [13], [65], [69]. These concerns were explicitly exemplified in an extensive review of mobile learning projects conducted by Frohberget et al. [16], who argued that, while the "tool support of most projects is not pedagogically ambitious, a strong minority provides tools that aim at realizing higher pedagogical goals". Ford and Leinonen [66] suggested separating "mobile learning" into "mobile" and "learning" and argued that the learning aspect is the most important concept. For them, the computing device just happens to be mobile; what is important is the instructional design and the learning activities. Their argument highlights a problematic bias in technology determinist research projects—they tend to dismiss the most important part of mobile computer-supported learning.

One explanation for the lack of pedagogical ambitions in the early years of research might be, as Sharples et al. [7] argued, that "evaluations of mobile learning systems and applications often show that learners, children and adults alike, enjoy using mobile devices for learning and report increased motivation as a result of this use". Tiene and Luft [70] in turn pointed out that it is common in any technology-rich learning context for students to be motivated and focused because of the tools themselves and the learning opportunities they facilitate. However, the stimulation of the technology itself or technology-rich contexts are not sufficient conditions for ensuring motivation and focus among learners [39].

To ensure learner engagement, a proper pedagogical or lesson design is needed when enthusiasm about using the new technologies begins to fade [39]. However, although many scholars, most notably Roschelle and Pea [17], have predicted tensions between traditional learning models, which are highly centralized, and emerging pedagogical ideas amplified with mobile technologies that are naturally situated, collaborative, and distributed, educational technologists tend to create applications that are designed to work within inherited educational ideas rather than to transform them [34].

As described above, most of the profound ideas about mobile computer-supported learning have been suggested by Roschelle and Pea [17] in their seminal paper about wireless internet learning devices. Such devices are small and powerful networking computing devices intended for personal use [17], [19], [66]. Although Roschelle and Pea's paper included seminal ideas about the educational use of mobile devices, they also described functions of the second-generation "mobile learning" tools: i) size and portability, ii) a small screen size (although contemporary tablet computers challenge this argument a bit), iii) computing power and a modular platform, iv) communication ability through multiple wireless networks, v) a wide range of available multipurpose applications, vi) ready ability to synchronize and backup with other computers, and vii) a stylus-driven interface (technology development has made this category obsolete). In practice, the characteristics described above fit our current smartphone and internet tablet lineup, providing a relevant case to consider for learning outside of schools and other educational contexts, as well as to consider a possibility to bring students' own devices into educational contexts [71].

Furthermore, Roschelle and Pea [17] predicted how mobile technology might revolutionize the role of teachers by breaking the contrastive teaching paradigms of "sage on the stage" (teacher-centered instruction) and "guide by side" (teacher-guided discovery); instead, they offered the idea of a "conductor of performances," which has been further developed by other scholars [49] using the term "orchestration" to describe run-time adjustments in complex socio-technical designs that include multiple social planes in different contexts mediated by multiple devices. On the other hand, many recent research projects in the computer-supported collaborative learning (with or without mobile devices) field have reduced or negated the role of teachers in supporting collaboration. These socio-constructivist projects have typically aimed at enhancing interactions in virtual environments without real-time teacher support [49]. However, an emerging idea of orchestration aims to supplement this approach with a teacher's timely support (when it is possible) and focus on flexible ways of arranging collaboration [72]. Simultaneously, there is increased interest in longer-term research projects where mobile tools are increasingly integrated into daily school activities at the curricular or practical levels [73], [74].

2.2.1 *Case Study 2: Field Trip to a Nature Park in a Wilderness Forest Setting in the Context of Informal K-12 Education*

The design of the second case study was influenced by the development of macro-scripting in CSCL, as it was one scenario in a mobile support for integrated learning -project. In this project, Dillenbourg et al. [75] expanded the scope of collaboration scripts presented by Dillenbourg [18] to encompass more than just small group interaction by introducing sets of pre- and post- structuring activities that were called a didactic envelope.

The participants in the second case study were primary school students ($N = 22$, all 12 years of age) who participated in a one-day learning project during a field trip to a nature park in a wilderness forest setting in northern Finland. The field trip activities in this case study were designed and developed by the research team in collaboration with the nature park's local expert, a biologist. The students were randomly assigned to eight groups (six triads and two dyads), and each group was provided with a mobile phone. Before the experiment, the principles and procedures of collaborative inquiry learning and argumentation were presented, and practical training for the field trip was given in the classroom by the researchers and the biologist.

The project task in this study was to explore inanimate and animate traces of nature in small groups to create argumentative knowledge claim messages [53]. This project is an example of a teacher-led outdoor learning

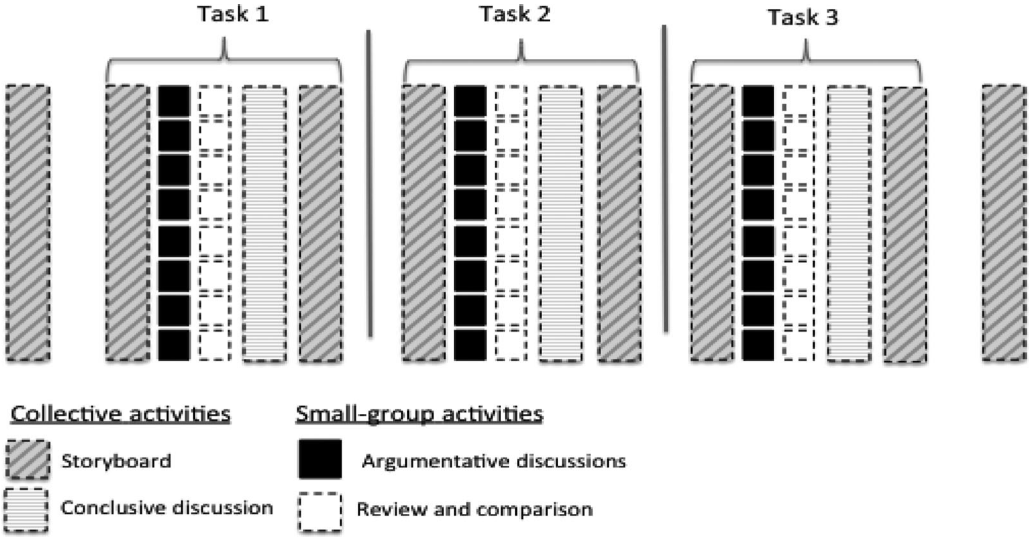

Fig. 4. Instructional design of the second case study.

activity in which students learn in groups within confined time periods, which is a subtype of "formal learning in informal settings" [76].

From the perspective of instructional design (see Fig. 4), a collaborative core activity was aimed at scaffolding the co-construction of argumentative discussions in small groups during inquiry learning [77]. It consisted of "soft" scaffolding, provided by tutors and the nature guide, and "hard" argumentation scaffolds, provided by the messaging tool (sentence openers). In addition, the instructional design included pre-structuring activities that provided procedural scaffolding in the form of storyboard messages [53] as well as post-structuring activities that included debriefing activities such as a review and comparison phase in the collaborative and conclusive synthesis at the end of each task at the collective level.

2.2.2 *Case Study 2: Technology Used in the Case Study*

The tools used were smartphones and a prototype of a mobile peer-to-peer messaging application called Flyer. Flyer is an example of a social proximity application that belongs to an emerging class of mobile networks: mobile encounter networks. The technology used created a digital "sphere," "field," or "aura" surrounding each group by enabling their phones to broadcast information to and fetch information from nearby groups or storyboard phones (see Figs. 5 and 6) directly without connection to a network or server [cf. 77]. Information in this digital realm was used to support and augment existing collaborative inquiry learning practices in a real space instead of using it as a collaboration tool per se. The application of Flyer was adapted to suit collaborative and argumentative inquiry learning by employing a design that embedded procedural and metacognitive scaffolding into the system's interface design in the form of knowledge claim message templates and fixed storyboard messages. The following section describes the features of the Flyer prototype [53].

Creating flyers. In practice, students were asked to edit Flyer templates from saved Flyer folders (see Fig. 5A). The Flyer editor allowed users to add a title, text, and image and to choose the background color. To constrain the argumentative discussion, student groups were cued to the main components of the knowledge claim message (metacognitive scaffolding) by the templates, which specified the components in reasoning from data to claim in the form of embedded sentence openers. Furthermore, the sentence openers were provided as suggestions; students were able to ignore the openers, change them, or create new ones. The

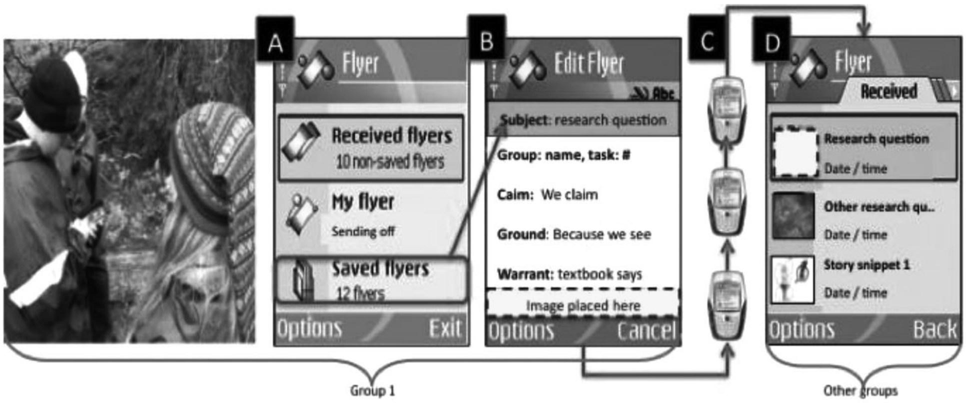

Fig. 5. Left: students working with a phone; A & B: Editing a knowledge claim message; C & D: Publishing and receiving a message.

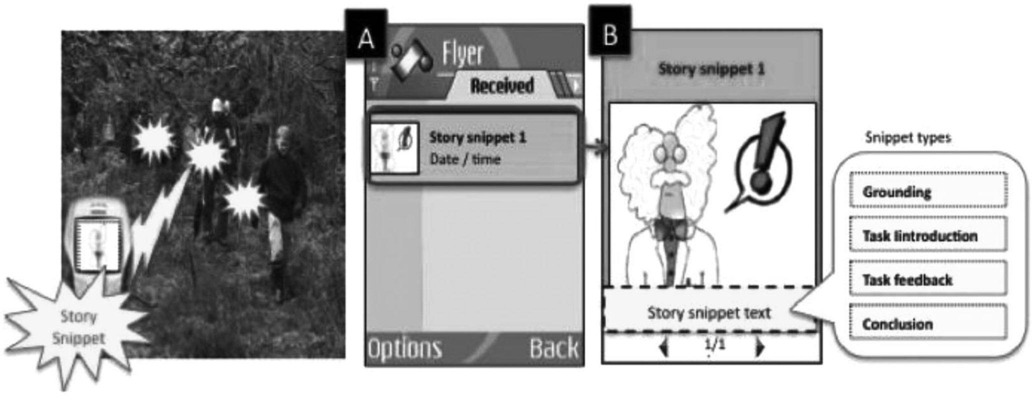

Fig. 6. Left: Pushing storyboard messages; Right (A & B): Receiving a storyboard message.

suggested sentence openers were always present and available to the students through the learning phases in each template and provided five pre-defined structural components (see Fig. 5B): (field 1) a research question for expressing group-level presumptions; (fields 2 through 4) sentence openers for knowledge claim creation (e.g., claims, grounds, and warrants); and (field 5) a photographic image (visual representation that supported the group's claim).

Background receiving. This feature scanned the environment for other Flyer users and Bluetooth devices and presented the identified storyboard and knowledge claim messages in a list (Figs. 6A, and 5D). The list displayed the subject of the message and the date and time that the message was received. In practice, the storyboard messages functioned as activity placeholders (procedural scaffolding) for each of the four learning phases, while knowledge claim messages were artifacts created by the students. The former were automatically pushed to the student groups' phones at appropriate phases or places along the nature trail before and after students' activities, and the latter were spread to peer phones after they were published manually by the student dyads/triads.

2.2.3 Empirical Evidence from the Second Case Study

In the second case study, to ensure that collaborative learning took place in the designed learning activities, collaboration scripts were used. However, the results of the second case study showed that this instructional design was partly flawed. Although the design was likely to promote important types of argumentative discussions this was not clearly achieved because the epistemological quality of co-constructed knowledge claim messages (Flyers) was revealed to be superficial and almost all discussions in each group were concentrated in the phase of argumentative discussions leaving other phases to be almost purely teacher-led activities [53].

The results suggest that the likely aim of the learners was "completing the learning environment" rather than participating in the inquiry process itself [79]. Alternately, these results may suggest also that the learners' main challenge or goal had been to meet the perceived requirements posed by the design of the experiment by using tutors and peers as a shortcut learning resource—an approach referred to as "soft" scaffolds [80], in contrast to "hard" scaffolds provided by the Flyer messaging tool [53].

Contrary to the explicit failures with ever-present technological scaffolds for the co-construction of knowledge claim messages (Flyers), co-construction dominated the recorded discussions in the inquiry groups and did drive some of the argumentation. It can be argued that, without mobile support, there would have been almost no argumentation and no learning by any of the students [53].

This second case study provides a clear indication as to how the educational use of ubiquitous computing progressed in our context: from minimal instructional design and un-mature technological tools (case study 1) to the distributed scaffolding (tutors, other students and mobile device) and ideas of integrated learning where a mobile device is just one agent in the system of actors and tools (case study 2).

2.3 Era of Social Mobile Learning: Combining Affordances of Social Software and Mobile Learning

Personal, portable, and wirelessly networked technologies are becoming more prevalent in the lives of learners, and simultaneously, social media has created new ideas about what it means to participate in educational activities [81], [82], [83]. Milrad and Multisilta [83] coined the term "mobile social media" to describe the integration and interplay between these two emergent technologies. In its simplest form, mobile social media makes possible situated updating and access to one's weblog. In other words, the use of mobile social media turns students' acts into artifacts [17]. At their best, social mobile media tools can be used for creating a "personalized-to-social learning activity" [84] where mobile devices are used as an integral part of a pedagogical design consisting of individual and collective learning activities [54].

However, these outcomes are not due to the technology alone, but also to the frameworks of "participation" and "sharing" that enable, structure, and call upon us to enact [85], reflecting societal changes such that social software has become an important element in our culture [86]. Much has been written on the benefits of blogs [87], [88], [89], [90], wikis [88], [90], [91], [92], and social networking sites [93] in education, but very little formal research focusing on the integration of multiple social software tools and mobile devices in higher education pedagogy has been published so far [54], [90], [94].

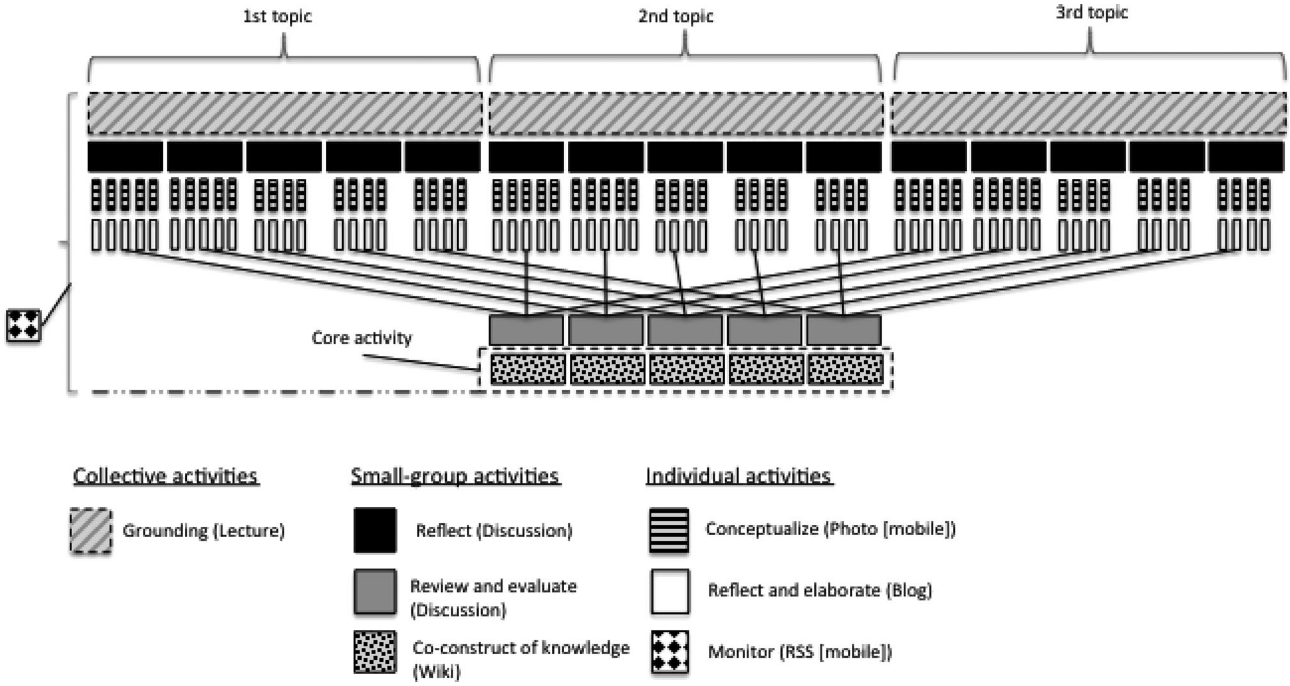

Fig. 7. Instructional design of the third case study.

The interplay between Web 2.0 tools and mobile technologies poses new challenges in supporting collaborative learning, as teachers have to integrate these new technologies into more or less traditional learning methods, curricula, and everyday school life [95]. "While educators have harnessed the web to develop formal e-learning platforms, many are struggling to unleash the power of social media to support learning. In part this is due to perceived difficulties in integrating its emergent fluid norms and meanings into highly structured learning environments" [83 p. 5].

New affordances provided by mobile devices and social software tools together lead us into a new phase in the evolution of technology-enhanced learning, one that forges new learning spaces and continuity between the pedagogical phases of instructional design [54], [74], [76]. In practice, the increasing use of social mobile media in education is stitching the learners' formal and informal learning contexts together and bridging individual and social learning, leading toward seamless learning.

However, most of the reviewed papers in the extensive literature review done by Wong and Looi [76] either tended to discuss or analyze personalized and social learning in their studies separately or only focus on one aspect. Furthermore, very few papers discussed the mechanisms of bridging the individual and collaborative activities. In this paper, the third case study is focused on bridging individual and collaborative activities as well as face-to-face and mobile social media activities.

2.3.1 *Case Study 3: Future Scenarios and Technologies in Learning: A Course in the Context of Higher Education*

In the third case study, the participants were 21 undergraduate students in a five-year teacher education program at the Faculty of Education at the University of Finland. All students were enrolled in a required course titled Future Scenarios and Technologies in Learning during the spring semester of 2009. The 21 participants comprised 16 women (76 percent) and five men (24 percent). The prevalence of women reflected the gender ratio of education majors at the university. The mobile phone-mediated activities in this course are an example of course-related activities outside of the normal class hours, such as artifact creation in daily life (largely incidental encounters or improvizations), which is another subtype of formal learning in informal settings [76].

In this case study, the same content was addressed multiple times when students encountered multiple representations of each of the content topics (six altogether) using different analogues, examples, and metaphors. In other words, the instructional design required students to revisit "the same material, at different times, in rearranged contexts, for different purposes and from different conceptual perspectives" [93 p. 28]. From the perspective of ill-structured problems and tasks, the students split one problem into multiple smaller problem-solving tasks as phases in the instructional design proceeded.

In this study, the learners' core task was to integrate selected individual blog reflections and visual representations into a coherent and comprehensive wiki (see Fig. 7). Although this wiki was also the main outcome of the activity (the end goal for their activities), it was not specified as such. There were also multiple individual and collective phases before the wiki activity, and the goals for these were not specified either.

The students needed to make choices in three phases concerning their learning objectives that aimed at solving ill-structured problems:

1). *Reflection (collaborative)*. After a grounding lecture, the students discussed the lecture topic in groups

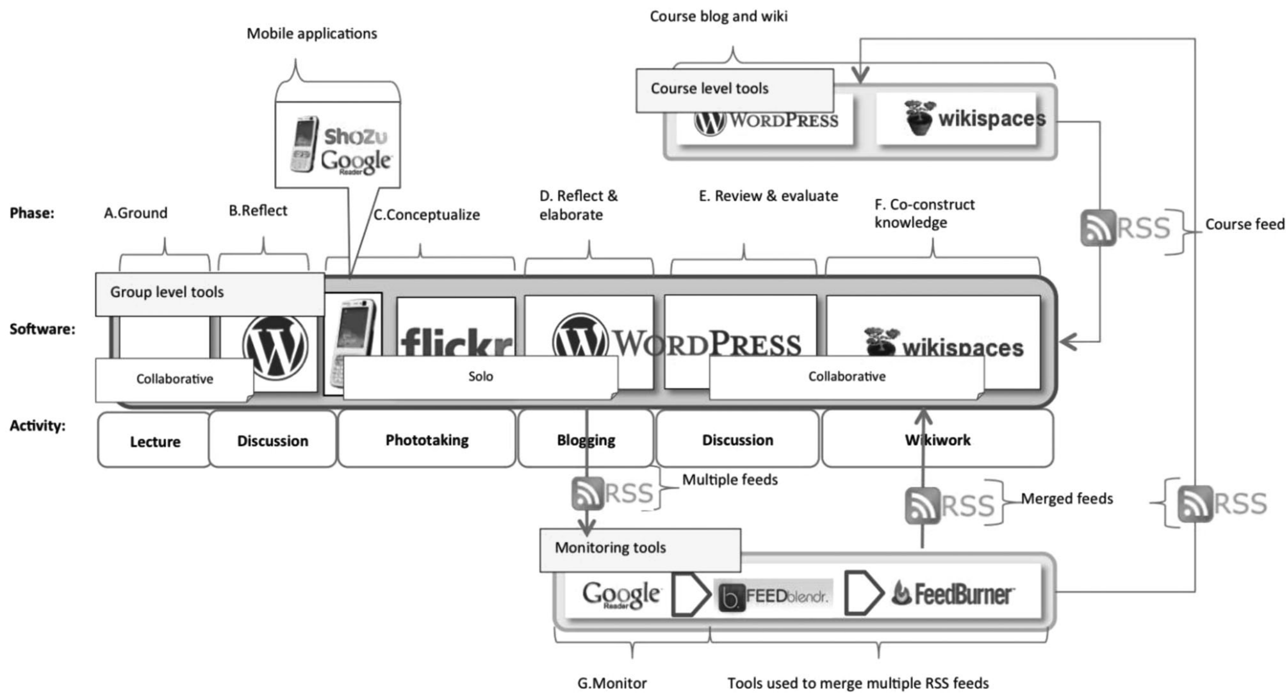

Fig. 8. Socio-technical design of the course.

and formulated a problem to be solved during the following individual learning phases;

2) *Conceptualization (individual)*. This phase included an activity in which students were required to conceptualize their group members' shared interests (i.e., a shared problem); this task can be considered a standalone, ill-structured task that led students to qualitative modeling to reformulate group-level problems;
3) *Knowledge co-construction (collaborative)*. This phase involved an assigned task focused on integrating each group's selected blog entries and photos into a cohesive and comprehensive group wiki; this activity could not be conducted without qualitative modeling to reformulate shared learning objectives and problems because individual activities affected the shared objectives and problems.

The instructional design of the third experiment enabled students to make comparisons between the cases. This was done both in face-to-face activities and with the help of technological tools. The activities involving the comparison comprised two phases:

1) *Reflection and elaboration (individual)*. After individual conceptualization, students were required to analyze photos taken using mobile phones to discard ideas that were not relevant to their groups' shared learning objectives; they were also required to write blog entries on selected photos, in which they further elaborated upon associations between the photos, group-level objectives, and students' everyday situated practices (note: students were able to see photos taken and blog entries written by other students and in other groups by monitoring their activities using an RSS reader);
2) *Review and evaluation (collaborative)*. After individual reflection and elaboration, students were tasked with reviewing group members' blogs and evaluating the usefulness of blog entries in the context of their shared learning objectives.

2.3.2 Case Study 3: Technology Used in the Case Study

The socio-technical design of the second case study consisted of recurrent individual and collective phases where students used multiple Web 2.0 tools and mobile phones in concert to perform designed tasks (Fig. 8) [97].

First, all students received a personal mobile multimedia computer that was integrated with features including a 3.2 megapixel digital camera, 3G connectivity, and an internet browser. The mobile device was the main tool for the students in Phase C; they were required to identify and capture situated pictorial metaphors describing their group's shared interests.

The device was equipped with a ShoZu cloud-based file-sharing tool that was used as a bridge to connect mobile phones to the Flickr cloud-based file-sharing service for photos. ShoZu offered functions to add tags, titles, and descriptions before putting photos on the Flickr photostream. In addition, the phone's web browser was configured to show students' accounts on the Google Reader Mobile cloud-based RSS aggregator. This service was used to show all of the course-related content on the mobile phones at the students' disposal (Fig. 8).

Second, an individual Wordpress.com account was created for each student. This blogging service was used as a personal learning diary for the students, where they individually reflected further on their ideas by writing journal entries regarding the respective pictures/videos sent to blogs via the Flickr file sharing service (Phase C). The students' blogs were used to store their group's shared working problems (Phase B) and as an anchor resource in the review and evaluation phase (Phase E). In addition, the blogging service was the platform for the course-level activities, a place for course-related announcements.

The cloud-based Wikispaces wiki service was also used for two purposes: first, it offered collaboration tools for the groups to use (i.e., an empty wiki page and a discussion tool) to support their collaborative knowledge co-construction (Phase F). Second, it was used at the course level for distributing resources (i.e., course curricula, lecture slides, hyperlinks, and how-to guides) and displaying syndicated content from Flickr (student accounts) and WordPress (course blog and student blogs).

In addition, FeedBlendr and FeedBurner RSS services were used to merge individual, group, and class-level feeds from multiple Flickr, WordPress, and Wikispaces accounts. In practice, these merged feeds were included as RSS widgets in a sidebar of the respective blog or wiki. These tools enabled the students to bind social software tools together and may be seen as additional collaborative tools that facilitated relationships between different task phases, the students, the content they produced, and the tools used in this study [98].

2.3.3 Empirical Evidence from Case Study 3

In this case, an explorative Bayesian classification analysis revealed that the best predictors of good learning outcomes were wiki-related activities. According to the Bayesian dependency model, students who were active in conceptualizing issues by taking photos were also active blog reflectors and collaborative knowledge builders in their groups. In general, the results indicated that interaction between individual and collective actions tended to increase individual knowledge acquisition during the course [54].

The third case study included full activity design, as suggested by [76], that included multiple phases. A mobile mediated conceptualization activity was just one phase of the instructional design. Products created during that phase can be characterized as artifacts, which were used as a mediating tool for reflections, elaborations, reviews, and knowledge building [76].

It can be concluded that the carefully crafted pedagogical activities and Web 2.0 tools used together to perform designed tasks probably increased students' individual knowledge acquisition during the course in the second case study. This is in accordance with Meyer's [99] claim regarding how assignments should be structured and orchestrated to encourage learning. It also reinforces the findings of [87] that a "technological tool works better when it is coupled with compatible pedagogical conceptions," and yet "interaction is insufficient to achieve cognitive engagement [because s]ome type of facilitation in online environments is necessary."

2.4 Ubiquitous Tomorrow: Learning Environment Consisting of an Amalgam of Tools Around the Corner

The world is entering the age of mobilism [19]. New technology tools fit more readily and naturally into our lives; increasingly broad, inexpensive, and easy access to internet wireless devices and a variety of web-based personal publishing and social software tools are making computing truly a ubiquitous and "continuous" part of our lives [19, p. 49]. What is important is the fact that "essentially anyone who wants mobile device can afford to purchase one ... cost is (almost) no longer a barrier to owning and operating an internet-connected personal computing device" [18, p. 4]. Furthermore, the adoption of mobile devices has been quite rapid, as smartphone sales surpassed global PC shipments for the first time in history in 2010, and it is further predicted that sales are going to surpass those of feature phones this year.

Ubiquitous computing has evolved from Weiser's, Kay's, and Papert's initial ideas about the interplay between the human world and communication technologies with the widespread adoption of mobile devices that require more proactive involvement than calm computing suggested originally by Weiser. Mobile phones have grown beyond a tool for conversations to become connected computing devices that offer a multitude of services [66], [100] and are currently perceived as more than just phones; they are now movie players, gaming platforms, cameras, etc. [34], [71], [101]. Current trends are also increasingly focusing on effective personal learning environments characterized by an amalgam of technology devices, software, and services; access to a variety of digital tools simultaneously for everyone, anytime, and anywhere; and choices about what technology is most appropriate in a given situation [102], [103].

Many recent ideas have concentrated on context-aware technology following contemporary human–computer-interaction paradigms (RFID tags, QR codes, GPS, etc.), which are now becoming mainstream in current mobile devices. The just-in-time and contextualized information afforded by these devices can serve as evidence to support partially formed ideas and misunderstandings, to trigger comparison with previously stored data on the devices, and to support an inquiry process or dialogue in situ. These affordances are enabling us to prepare instructional designs based on the ideas suggested a decade ago by Roschelle and Pea [17].

In many countries, students can now have one or more device each if needed, and the number of devices in the ubiquitous environment is not stable. The device-user ratio ranges from the use of multiple computing devices (such as sensors) by one student (10:1) to a class of students to one interactive whiteboard (1: all), including the in-between usage scenarios of 1:1 (as G1:1 initiative members originally suggested), 1:2 (as in pair work sharing a device), and 1:4 (as in small group work discussed and mediated by a shared device [76]. The increasing number of devices per user poses new challenges for instructional designers because each ratio provides different dynamics of interaction and collaboration [76].

In other words, the different device-student ratios are an example of converged cognitive tools that we unconsciously and effortlessly use to achieve the benefits of distributed intelligence [71], [104]. From an educational perspective, it is a part of an environment where "all students have access to a variety of digital devices and services, including computers connected to the internet and mobile computing devices, whenever and wherever they need them" [101, p. 6]. It is also in line with tenets of constructivism because it is a learning environment where both teachers and students are active participants in the learning processes (analyzing information critically, creating new knowledge in a variety of ways, and communicating what they have learned) mediated by tools that they have chosen and are appropriate for particular tasks [102].

3 Discussion

Overall, decades of research in the field of the educational use of ubiquitous computing and rapid technological evolution (both described in Fig. 1) illustrate the rich field of research and development opportunities. van Lente et al. [106] have argued that hype thrives in rich environments, where research, business, and wider social activities contribute to the creation, sharing, and refinement of expectations. This paper follows studies conducted by Järvenpää and Mäkinen [107] and van Lente et al. [106], which have bridged empirical measures to the hype cycle. Our paper represents an exploratory and empirically driven approach seeking indicators in the three case study designs for the hype cycle in relation to the evolution of the educational use of ubiquitous computing.

This paper goes against technology-determinism in showing how important it is to design, develop and deliver lightweight digital tools and activities for learners to construct knowledge when researching contemporary phenomena in the field of technology-enhanced learning.

Currently, the major challenge in the technology-enhanced learning field is the overemphasis on designing tools and instructional activities for sharing and communicating, while the potential role of tools and appropriate instructional design for guiding and supporting learning processes has been virtually ignored [108].

Our claim is that seamless learning can be one productive way for schools and other educational institutions to promote learning skills, namely self-regulated learning and collaboration, and to prepare people for the 21st-century learning society [109]. We should move our emphasis on how to exploit affordances of emerging and contemporary technology (Section 2.4, ubiquitous tomorrow) in order to support or promote self-regulated learning.

To advance research on self-regulated seamless learning, we propose design guidelines for *self-regulated seamless learning*. Self-regulated and strategic learning characterizes second-order learning skills, e.g., the effective use of strategies, such as planning, setting goals, organizing, and monitoring [110]. Monitoring the learning process is an essential element of self-regulated learning. The learner must be able to control his/her attention, select adequate learning strategies, identify errors, diagnose difficulties and their causes, and adapt learning activities accordingly.

Besides cognitive and metacognitive skills, learning motivation plays a central role in self-regulated learning. To maintain learning motivation, learners need to be able to control their feelings, handle success and disappointments appropriately, and delay wishes and desires that are not linked to the intended learning aims [111]. Today, pressure toward active learning and engagement in shared learning situations is increasing, so regulating learning is rarely a solitary task [108].

We argue that seamless learning opportunities with mobile devices and educational designs that implement theoretical ideas of self- and socially shared regulation of learning can offer new opportunities for developing inspiring, and engaging learning environments.

To conclude, this paper reinforces the idea suggested by Jeremy Roschelle 10 years ago [112] that we should focus on rich pedagogical practices and simple (mobile) tools. In the context of the three case studies described in this paper, the role of instructional design increased and that of mobile tools decreased from case to case (as the research progressed). In contrast to early years of the research on mobile computer-supported learning, it can now be stated that it is not only the learner being "mobile" that matters. A stronger argument for applying mobile tools for education is that of increasing students' opportunities for interactions and sharing ideas and thus increasing opportunities for an active mind in multiple contexts [113].

References

[1] M. Weiser, "The computer for the 21st century," *ACM SIGMOBILE Mobile Comput. Commun. Rev.*, vol. 3, no. 3, pp. 3–11, 1991.

[2] S. B. Barnes, "Alan Kay: Transforming the computer into a communication medium," *IEEE Ann. Hist. Comput.*, vol. 29, no. 2, pp. 18–30, Apr. 2007.

[3] S. Feldman, "A conversation with Alan Kay," *ACM Queue*, vol. 2, no. 2, pp. 13–22, 2004.

[4] A. C. Kay, "A personal computer for children of all ages," in *Proc. ACM Nat. Conf.*, 1972, p. 1.

[5] S. Papert, *Mindstorms: Children, Computers, and Powerful Ideas*. New York, NY, USA: Basic Books, 1980, p. 230.

[6] J. Piaget, *The Origins of Intelligence in Children*. New York, NY, USA: International Universities, 1952, p. 419.

[7] M. Sharples, I. Sanchez, M. Milrad, and G. Vavoula, "Mobile learning: Small devices, big issues," in *Technology Enhanced Learning: Principles and Products*, N. Balacheff, S. Ludvigsen, T. Jong, A. Lazonder, and S. Barnes, Eds. New York, NY, USA: Springer, 2009, pp. 233–249.

[8] J. Fenn. (2007). "Understanding Gartner's hype cycles, [Online]. Available: http://www.gartner.com/DisplayDocument?id=509085

[9] D. O' Leary, "Gartner's hype cycle and information system research issues," *Int. J. Account. Inf. Syst.*, vol. 9, no. 4, pp. 240–252, 2008.

[10] A. Collins, D. Joseph, and K. Bielaczyc, "Design research: Theoretical and methodological issues," *J. Learn. Sci.*, vol. 13, no. 1, pp. 15–42, 2004.

[11] P. W. Williams, "Assessing mobile learning effectiveness and acceptance," Ph.D. dissertation, Faculty School Business, George Washington Univ., Washington, DC, USA, 2009.

[12] A. Trifonova, "Mobile learning-review of the literature," Dept. Inf. Commun. Technol., Univ. Trento, Trento, Italy, Tech. Rep. No DIT03009, 2003.

[13] Y. Park, "A pedagogical framework for mobile learning: Categorizing educational applications of mobile technologies into four types," *Int. Rev. Res. Open Distance Learn.*, vol. 12, no. 2, pp. 78–102, 2011.

[14] C. Quinn. (2000). "mLearning: Mobile, wireless, in-your-pocket learning," *LiNE Zine e-Magazine*, [Online]. Available: http://linezine.com/2.1/features/cqmmwiyp.htm

[15] D. Keegan, "The incorporation of mobile learning into mainstream education and training," in *Proc. World Conf. Mob. Learn.*, Sep. 2005, vol. 2008, no. 17, pp. 1–17.

[16] D. Frohberg, C. Göth, and G. Schwabe, "Mobile learning projects—A critical analysis of the state of the art," *J. Comput. Assisted Learn.*, vol. 25, no. 4, pp. 307–331, Jul. 2009.

[17] J. Roschelle and R. Pea, "A walk on the WILD side: How wireless handhelds may change computer-supported collaborative learning," *Int. J. Cognition Technol.*, vol. 1, no. 1, pp. 145–168, 2002.

[18] P. Dillenbourg, "Over-scripting CSCL: The risks of blending collaborative learning with instructional design," in *Three Worlds CSCL Can We Support CSCL*. Heerlen, Netherlands: Open Universiteit Nederland, 2002, pp. 61–91.

[19] C. A. Norris and E. Soloway, "Learning and schooling in the age of mobilism," *Educ. Technol.*, vol. 51, no. 6, pp. 3–10, 2011.

[20] W. Roush, "Social machines: Computing means connecting," *Technol. Rev.*, vol. 2005, no. 3, p. 5, Aug. 2005.

[21] V. Bellotti and S. Bly, "Walking away from the desktop computer," in *Proc. ACM Conf. Comput. Supported Cooperative Work*, 1996, pp. 209–218.

[22] P. Luff and C. Heath, "Mobility in collaboration," in *Proc. ACM Conf. Comput. Supported Cooperative Work*, 1998, pp. 305–314.

[23] V. Freiman, J. Beauchamp, S. Blain, N. Lirette-Pitre, and H. Fournier, "Does one-to-one access to laptops improve learning: Lessons from New Brunswick's individual laptop school initiative," *Procedia Soc. Behav. Sci.*, vol. 2, no. 2, pp. 5686–5692, 2010.

[24] S. Rockman, "Learning from laptops," *Threshold*, vol. 1, pp. 24–28, 2003.

[25] M. Trimmel and J. Bachmann, "Cognitive, social, motivational and health aspects of students in laptop classrooms," *J. Comput. Assisted Learn.*, vol. 20, no. 2, pp. 151–158, Apr. 2004.

[26] R. Rieger and G. Gay, "Using mobile computing to enhance field study," in *Proc. 2nd Int. Conf. Comput. Support Collaborative Learn.*, 1997, pp. 218–226.

[27] N. Shin, C. Norris, and E. Soloway, "Findings from early research on one-to-one handheld use in K-12 education," in *Ubiquitous Computing in Education Invisible Technology Visible Impact*, M. van't Hooft and K. Swan, Eds. Hillsdale, NJ, USA: Lawrence Erlbaum Assoc., 2006, pp. 19–39.

[28] A. R. Crowe, "Learning to teach with handheld computers," in *Ubiquitous Computing in Education Invisible Technology Visible Impact*, M. van't Hooft and K. Swan, Eds. Hillsdale, NJ, USA: Lawrence Erlbaum Assoc., 2007, pp. 127–145.

[29] S. Hennessy, "The potential of portable technologies for supporting graphing investigations," *Brit. J. Educ. Technol.*, vol. 30, no. 1, pp. 57–60, 1999.

[30] V. Crawford, P. Vahey, A. Lewis, and Y. Toyama, "Palm education pioneer program - march 2002 evaluation report," SRI International, Estados Unidos, 2002.

[31] P. Vahey, D. Tatar, and J. Roschelle, "Using handheld technology to move between the private and public in the classroom," in *Ubiquitous Computing in Education Invisible Technology Visible Impact*, M. van't Hooft and K. Swan, Eds. Hillsdale, NJ, USA: Lawrence Erlbaum Assoc., 2006, pp. 187–210.

[32] S. J. Metcalf and R. F. Tinker, "Probeware and handhelds in elementary and middle school science," *J. Sci. Educ. Technol.*, vol. 13, no. 1, pp. 43–49, Mar. 2004.

[33] R. F. Tinker and J. Krajcik, *Portable Technologies: Science Learning in Context. Innovations in Science Education and Technology*. Norwell, MA, USA: Kluwer, 2001.

[34] K. Squire and S. M. Dikkers, "Amplifications of learning: Use of mobile media devices among youth," *Convergance: Int. J. Res. New Media Technol.*, vol. 18, pp. 445–464, 2012.

[35] B. Patten, I. Arnedillosanchez, and B. Tangney, "Designing collaborative, constructionist and contextual applications for handheld devices," *Comput. Educ.*, vol. 46, no. 3, pp. 294–308, Apr. 2006.

[36] M. Curtis, K. Luchini, W. Bobrowsky, C. Quintana, and E. Soloway, "Handheld use in K-12: A descriptive account," in *Proc. IEEE Int. Workshop Wireless Mobile Technol. Educ.*, 2002, pp. 23–30.

[37] R. Pea and H. Maldonado, "WILD for learning: Interacting through new computing devices anytime, anywhere," in *Cambridge University Handbook of the Learning Sciences*. New York, NY, USA: Cambridge Univ. Press, pp. 852–886, 2006.

[38] M. Sharples, "Disruptive devices: Mobile technology for conversational learning," *Int. J. Continuing Eng. Educ. Life-Long Learn.*, vol. 12, nos. 5/6, pp. 504–520, 2002.

[39] C.-K. Looi, L.-H. Wong, H.-J. So, P. Seow, Y. Toh, W. Chen, B. Zhang, C. Norris, and E. Soloway, "Anatomy of a mobilized lesson: Learning my way," *Comput. Educ.*, vol. 53, no. 4, pp. 1120–1132, 2009.

[40] T.-W. Chan, J. Roschelle, S. Hsi, K. Kinshuk, T. Brown, T. Brown, C. Patton, J. Cherniavsky, R. Pea, C. Norris, E. Soloway, N. Balacheff, M. Scardamalia, P. Dillenbourg, C.-K. Looi, M. Milrad, and U. Hoppe, "One-to-one technology-enhanced learning: An opportunity for global research collaboration," *Res. Practice Technol. Enhanced Learn.*, vol. 1, no. 1, pp. 3–29, 2006.

[41] T. Brown, "Towards a model for m-learning in Africa," *Int. J. E-Learning*, vol. 4, no. 3, pp. 299–315, 2005.

[42] U. Hoppe, R. Joiner, M. Milrad, and M. Sharples, "Guest editorial: Wireless and mobile technologies in education," *J. Comput. Assisted Learn.*, vol. 19, pp. 255–259, 2003.

[43] V. Colella, "Participatory simulations: Building collaborative understanding through immersive dynamic modeling," *J. Learn. Sci.*, vol. 9, no. 4, pp. 471–500, 2000.

[44] E. Klopfer and K. Squire, "Environmental detectives—The development of an augmented reality platform for environmental simulations," *Educ. Technol. Res. Develop.*, vol. 56, no. 2, pp. 2364–2381, 2008.

[45] S. Price, Y. Rogers, D. Stanton, and H. Smith, "A new conceptual framework for CSCL: Supporting diverse forms of reflection through multiple interactions," in *Proc. Int. Conf. Comput. Supported Collaborative Learn.*, 2003, pp. 513–522.

[46] Y. Rogers, S. Price, G. Fitzpatrick, R. Fleck, E. Harris, H. Smith, C. Randell, H. Muller, C. O'Malley, D. Stanton, M. Thompson, and M. J. Weal, "Ambient w: Designing new forms of digital augmentation for learning outdoors," in *Proc. Conf. Interact. Des. Children*, 2004, pp. 3–10.

[47] K. Squire and H. Jenkins, "Harnessing the power of games in education," *Insight*, vol. 3, no. 1, pp. 5–33, 2003.

[48] A. L. Abrahamson, F. F. Hantline, M. G. Fabert, M. J. Robson, and R. J. Knapp, "Electronic classroom system enabling interactive self-paced learning," US Patent 5002491, Mar. 26, 1991.

[49] P. Dillenbourg and P. Jermann, "Technology for classroom orchestration," in *New Science of Learning Cognition Computers and Collaboration in Education*, M. S. Khine and I. M. Saleh, Eds. New York, NY, USA: Springer, 2010, pp. 1–20.

[50] R. J. Dufresne, W. J. Gerace, W. J. Leonard, J. P. Mestre, and L. Wenk, "Classtalk: A classroom communication system for active learning," *J. Comput. Higher Educ.*, vol. 7, no. 2, pp. 3–47, 1996.

[51] D. Corlett, M. Sharples, S. Bull, and T. Chan, "Evaluation of a mobile learning organiser for university students," *J. Comput. Assisted Learn.*, vol. 21, no. 3, pp. 162–170, Jun. 2005.

[52] J. Niramitranon, M. Sharples, and C. Greenhalgh, "Orchestrating learning in a one-to-one technology classroom," in *Proc. IEEE 6th Int. Conf. Wireless Mobile Ubiquitous Technol. Educ.*, 2010, pp. 96–103.

[53] J. Laru, S. Järvelä, and R. B. Clariana, "Supporting collaborative inquiry during a biology field trip with mobile peer-to-peer tools for learning: a case study with K-12 learners," *Interact. Learn. Environ.*, vol. 20, no. 2, pp. 103–117, Apr. 2012.

[54] J. Laru, P. Näykki, and S. Järvelä, "Supporting small-group learning using multiple Web 2.0 tools: A case study in the higher education context," *Internet Higher Educ.*, vol. 15, no. 1, pp. 29–38, Jan. 2012.

[55] M. Milrad and M. H. Jackson, "Designing and implementing educational mobile services in university classrooms using smart phones and cellular networks," *Int. J. Eng. Educ.*, vol. 24, no. 1, pp. 84–91, 2008.

[56] J. Laru and S. Järvelä, "Social patterns in mobile technology mediated collaboration among members of the professional distance education community," *Educ. Media Int.*, vol. 45, no. 1, pp. 17–32, Mar. 2008.

[57] S. Järvelä, K. Hakkarainen, L. Lipponen, and E. Lehtinen, "Creating computer supported collaborative learning in Finnish schools: Research perspectives on sociocognitive effects," *Int. J. Continuing Eng. Educ. Life-Long Learn.*, vol. 11, pp. 365–374, 2001.

[58] T. Leinonen, O. Virtanen, K. Hakkarainen, and G. Kligyte, "Collaborative discovering of key ideas in knowledge building," in *Proc. Conf. Comput. Support Collaborative Learn.*, 2002, pp. 529–530.

[59] T. Leinonen, G. Kligyte, T. Toikkanen, J. Pietarila, and P. Dean, *Learning with Collaborative Software: A Guide to Fle3*. Helsinki, Finland: Univ. Art Des. Helsinki, 2003.

[60] W. Rubens, B. Emans, T. Leinonen, A. G. Skarmeta, and R.-J. Simons, "Design of web-based collaborative learning environments. Translating the pedagogical learning principles to human computer interface," *Comput. Educ.*, vol. 45, no. 3, pp. 276–294, 2005.

[61] J. Laru and S. Järvelä, "Applying wireless technology for coordinating collaboration in distributed university teachers' team," in *Proc. Int. Conf. Comput. Support Collaborative Learn.*, 2003, pp. 77–79.

[62] E. Scanlon, A. Jones, and J. Waycott, "Mobile technologies: Prospects for their use in learning in informal science settings," *J. Interact. Media Educ.*, vol. 2005, no. 25, pp. 1–17, 2005.

[63] M. Sharples, "The design of personal mobile technologies for lifelong learning," *Comput. Educ.*, vol. 34, nos. 3/4, pp. 177–193, 2000.

[64] G. Zurita and M. Nussbaum, "A constructivist mobile learning environment supported by a wireless handheld network," *J. Comput. Assisted Learn.*, vol. 20, no. 4, pp. 235–243, Jul. 2004.

[65] S. Järvelä, P. Näykki, J. Laru, and T. Luokkanen, "Structuring and regulating collaborative learning in higher education with wireless networks and mobile tools," *Int. J. Eng.*, vol. 10, no. 4, pp. 71–79, 2007.

[66] M. Ford and T. Leinonen, "MobilED—Mobile tools and services platform for formal and informal learning," in *Mobile Learning: Transforming the Delivery of Education and Training*. Edmonton, Canada: AU Press, 2010, pp. 195–214.

[67] B. Freudenberg, Y. Ohshima, and S. Wallace, "One laptop per child," *Commun. ACM*, vol. 2009, no. 6, pp. 57–64, 2009.

[68] M. Leaning, "The one laptop per child project and the problems of technology-led educational development," in *High-Tech Tots: Childhood in a Digital World*, I. Berson and M. Berson, Eds. Charlotte, NC, USA: Information Age Publishing, 2010, pp. 1–29.

[69] N. Futurelab, L. Naismith, P. Lonsdale, G. Vavoula, and M. Sharples, "Literature review in mobile technologies and learning," Futurelab, Bristol, U.K., Tech. Rep. 11, 2005.

[70] D. Tiene and P. Luft, "Teaching in a technology-rich classroom," *Educ. Technol.*, vol. 41, pp. 23–31, 2001.

[71] R. Pea and H. Maldonado, "WILD for learning: Interacting through new computing devices anytime, anywhere," in *Cambridge Handbook of the Learning Sciences*, R. K. Sawyer, Ed. Cambridge, U.K.: Cambridge Univ. Press, 2006, pp. 427–441.

[72] R. Hämäläinen and K. Vähäsantanen, "Theoretical and pedagogical perspectives on orchestrating creativity and collaborative learning," *Educ. Res. Rev.*, vol. 6, pp. 169–184, Aug. 2011.

[73] J. Roschelle, K. Rafanan, G. Estrella, M. Nussbaum, and S. Claro, "From handheld collaborative tool to effective classroom module: Embedding CSCL in a broader design framework," *Comput. Educ.*, vol. 55, no. 3, pp. 1018–1026, 2010.

[74] C. Alvarez, R. Alarcon, and M. Nussbaum, "Implementing collaborative learning activities in the classroom supported by one-to-one mobile computing: A design-based process," *J. Syst. Softw.*, vol. 84, no. 11, pp. 1961–1976, 2011.

[75] P. Dillenbourg, P. Jermann, A. Weinberger, K. Stegmann, and F. Fischer, A framework for integrated learning scripts, Kaleidoscope, JEIRP MOSIL, Rep. Deliverable 23.4.1 [Online], Available: http://craftwww.epfl.ch/mosil/deliverables/D23-4-1.AVEC.pdf

[76] L.-H. Wong and C.-K. Looi, "What seams do we remove in mobile assisted seamless learning? A critical review of the literature," *Comput. Educ.*, vol. 57, no. 4, pp. 2364–2381, 2011.

[77] A. Weinberger, K. Stegmann, F. Fischer, and H. Mandl, "Scripting argumentative knowledge construction in computer-supported learning environments," in *Scripting Computer-Supported Collaborative Learning - Cognitive, Computational and Educational Perspectives*, vol. 6, F. Fischer, I. Kollar, H. Mandl, and J. M. Haake, Eds. New York, NY, USA: Springer, 2007, pp. 191–211.

[78] O. Volovikov, T. Juonoja, M. Weber, N. Kotilainen, M. Vapa, and J. Vuori, "Mobile encounter networks and their applications," in *Proc. IEEE 5th Consum. Commun. Netw. Conf.*, 2008, pp. 1176–1180.

[79] W. R. Van Joolingen, T. De Jong, and A. Dimitrakopoulou, "Issues in computer supported inquiry learning in science," *J. Comput. Assisted Learn.*, vol. 23, no. 2, pp. 111–119, 2007.

[80] P. Sharma and M. J. Hannafin, "Scaffolding in technology-enhanced learning environments," *Interact. Learn. Environ.*, vol. 15, no. 1, pp. 27–46, 2007.

[81] S. Lewis, R. Pea, and J. Rosen, "Collaboration with mobile media: Shifting from 'Participation' to 'Co-creation'," in *Proc. IEEE 6th Int.Conf. Wireless Mobile Ubiquitous Technol. Educ.*, 2009, pp. 112–116.

[82] C. Liu and M. Milrad, "Guest editorial—One-to-one learning in the mobile and ubiquitous computing age," *J. Educ. Technol. Soc.*, vol. 13, no. 4, pp. 1–3, 2010.

[83] J. Multisilta and M. Milrad, "Sharing experiences with social mobile media," in *Proc. 11th Int. Conf. Human-Comput. Interact. Mobile Devices Services*, 2009, pp. 1–3.

[84] L. Wong, C. Chin, C. Tan, and M. Liu, "Students' personal and social meaning making in a chinese idiom mobile learning environment," *Educ. Technol. Soc.*, vol. 13, no. 4, pp. 15–26, 2010.

[85] H. Jenkins, "Confronting the challenges of participatory culture: Media education for the 21st century," *Program*, vol. 21, no. 1, p. 72, 2006.

[86] S. Lewis, R. Pea, and J. Rosen, "Beyond participation to co-creation of meaning: Mobile social media in generative learning communities," *Social Sci. Inf.*, vol. 49, no. 3, pp. 351–369, 2010.

[87] O. Halic, D. Lee, T. Paulus, and M. Spence, "To blog or not to blog: Student perceptions of blog effectiveness for learning in a college-level course," *Internet Higher Educ.*, vol. 13, no. 4, pp. 206–213, 2010.

[88] A. Hemmi, S. Bayne, and R. Land, "The appropriation and repurposing of social technologies in higher education," *J. Comput. Assisted Learn.*, vol. 25, no. 1, pp. 19–30, 2009.

[89] Y. Xie, F. Ke, and P. Sharma, "The effects of peer-interaction styles in team blogs on students' cognitive thinking and blog participation," *J. Educ. Comput. Res.*, vol. 42, no. 4, pp. 459–479, 2010.

[90] S. Wheeler, "Learning space mashups: Combining web 2.0 tools to create collaborative and reflective learning spaces," *Future Internet*, vol. 1, no. 1, pp. 3–13, 2009.

[91] U. Cress and J. Kimmerle, "A systemic and cognitive view on collaborative knowledge building with wikis," *Int. J. Comput. Collaborative Learn.*, vol. 3, no. 2, pp. 105–122, 2008.

[92] T. Leinonen, T. Vadén, and J. Suoranta, "Learning in and with an open wiki project: Wikiversity's potential in global capacity building," *First Monday*, vol. 14, no. 2, pp. 1–4, 2009.

[93] N. Arnold and T. Paulus, "Using a social networking site for experiential learning: Appropriating, lurking, modeling and community building," *Internet Higher Educ.*, vol. 13, no. 4, pp. 188–196, 2010.

[94] H. Uzunboylu, H. Bicen, and N. Cavus, "The efficient virtual learning environment: A case study of web 2.0 tools and Windows live spaces," *Comput. Educ.*, vol. 56, no. 3, pp. 720–726, 2011.

[95] M. Arvaja, R. Hämäläinen, and H. Rasku-Puttonen, "Challenges for the teacher's role in promoting productive knowledge construction in computer-supported collaborative learning contexts," in *Online Learning Communities and Teacher Professional Development: Methods for Improved Education Delivery*, O. Lindberg and A. Olofsson, Eds. Hershey, PA, USA: IGI Global, 2009, pp. 263–280.

[96] R. Spiro, P. J. Feltovich, M. J. Jacobson, and R. L. Coulson, "Cognitive flexibility, constructivism, and hypertext: Random access instruction for advanced knowledge acquisition in ill-structured domains," *Educ. Technol.*, vol. 31, no. 5, pp. 24–33, 1991.

[97] J. Laru, P. Näykki, and S. Järvelä, "Supporting small-group learning using multiple Web 2.0 tools: A case study in the higher education context," *Internet Higher Educ.*, vol. 15, pp. 29–38, 2012.

[98] M. J. W. Lee, C. Miller, and L. Newnham, "RSS and content syndication in higher education: Subscribing to a new model of teaching and learning," *Educ. Media Int.*, vol. 45, no. 4, pp. 311–322, 2008.

[99] K. A. Meyer, "A comparison of Web 2.0 tools in a doctoral course," *Internet Higher Educ.*, vol. 13, no. 4, pp. 226–232, 2010.

[100] A. Greenfield, *Everyware: The Dawning Age of Ubiquitous Computing*. Upper Saddle River, NJ, USA: New Riders, 2006, p. 272.

[101] M. Satyanarayanan, "Swiss army knife or wallet? " *IEEE Pervasive Comput.*, vol. 4, no. 2. pp. 2–3, Apr. 2005.

[102] N. Dabbagh and A. Kitsantas, "Personal learning environments, social media, and self-regulated learning: A natural formula for connecting formal and informal learning," *Internet Higher Educ.*, vol. 15, no. 1, pp. 3–8, 2011.

[103] M. van't Hooft and K. Swan, *Ubiquitous Computing in Education—Invisible Technology, Visible Impact*. Hillsdale, NJ, USA: Lawrence Erlbaum Assoc., 2007.

[104] G. Fischer and S. Konomi, "Innovative socio-technical environments in support of distributed intelligence and lifelong learning," *J. Comput. Assisted Learn.*, vol. 23, no. 4, pp. 338–350, 2007.

[105] M. van't Hooft, K. Swan, and D. Cook, "What is ubiquitous computing," in *Ubiquitous Computing in Education*, M. Van, T. Hooft, and K. Swan, Eds. Hillsdale, NJ, USA: Lawrence Erlbaum Assoc., 2007, pp. 3–17.

[106] H. van Lente, C. Spitters, and A. Peine, "Comparing technological hype cycles: Towards a theory," *Technol. Forecasting Social Change*, vol. 80, pp. 1615–1628, 2013.

[107] H. Järvenpää and S. J. Mäkinen, "Empirically detecting the Hype Cycle with the life cycle indicators: An exploratory analysis of three technologies," in *Proc. IEEE Int. Conf. Ind. Eng. Eng. Manage.*, 2008, pp. 12–16.

[108] S. Järvelä and A. F. Hadwin, "New frontiers: Regulating learning in CSCL," *Educ. Psychol.*, vol. 48, no. 1, pp. 25–39, Jan. 2013.

[109] J. Laru and S. Järvelä, "Integrated use of multiple social software tools and face-to-face activities in order to support self-regulated learning: a case study in higher education context," in *Seamless Learning in the Age of Mobile Connectivity*, L.-H. Wong, M. Milrad, and M. Specht, Eds. New York, NY, USA: Springer, 2014.

[110] A. F. Hadwin, S. Järvelä, and M. Miller, "Self-regulated, co-regulated and socially shared regulation of learning," in *Handbook of Selfregulation of Learning and Performance*, vol. 30, B. J. Zimmerman and D. H. Schunk, Eds. New York, NY, USA: Taylor & Francis, 2011, pp. 65–84.

[111] H. Järvenoja and S. Järvelä, "Emotion control in collaborative learning situations: do students regulate emotions evoked by social challenges?" *Brit. J. Educ. Psychol.*, vol. 79, pp. 463–481, 2009.

[112] J. Roschelle, "Keynote paper: Unlocking the learning value of wireless mobile devices," *J. Comput. Assisted Learn.*, vol. 19, pp. 260–272, May 2003.

[113] P. Dillenbourg, S. Järvelä, and F. Fischer, "The evolution of research on computer-supported collaborative learning," in *Technology Enhanced Learning Principles and Products*, New York, NY, USA: Springer, 2009, p. 21.

Jari Laru received the MEd and PhD from the University of Oulu in 2003 and 2012, respectively. He has done his doctoral thesis "Scaffolding learning activities with collaborative scripts and mobile devices" in the context of the Doctoral Program for Multidisciplinary Research on Learning Environments funded by the Academy of Finland and Ministry of Education. He is currently a university lecturer (tenured). His research interests include the design of collaborative learning, emergent technologies in education, and using mobile devices as cognitive tools. He is a member of the EARLI and ISLS.

Piia Näykki received the MEd in educational psychology from the University of Oulu, Finland, in 2004. She was a project researcher from 2004 to 2007 and was funded by the Finnish Doctoral Program in Education and Learning and Finnish Doctoral Program for Multidisciplinary Research on Learning Environments. She is currently working toward the PhD degree in the field of learning sciences. Her research interests include the socio-emotional challenges and conflicts in collaborative learning, the process-oriented analysis of collaborative learning interaction, and the design of (computer-supported) collaborative learning. She is a member of the EARLI.

Sanna Järvelä is a professor in the field of learning and educational technology and a head of the Learning and Educational Technology Research Unit (LET) (http://www.let.oulu.fi/) in the Department of Educational Sciences, University of Oulu, Finland. Her main research interests include learning processes in technology-enhanced learning, self-regulated learning, and computer-supported collaborative learning. She has been an associate editor of *Learning and Instruction* (2010-2014). She is currently an editor of Frontline Learning Research and associate editor in the *International Journal of Computer Supported Collaborative Learning (IJCSCL)* and editorial board member in several scientific journals (e.g., *Educational Psychologist*, *Educational Research Review*). Her research projects involve supporting 21st century learning skills, especially the socially shared regulation of learning, in higher education.