Lecture Notes in Educational Technology

Chee-Kit Looi
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Christian Glahn
Su Cai *Editors*

Seamless Learning

Perspectives, Challenges and Opportunities

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Preface

Seamless learning happens when persons or groups experience a continuity of learning, and consciously bridges the multifaceted learning efforts, across a combination of locations, times, technologies, or social settings. As further advances in research related to seamless learning are made, new and different visions, researches and practices on seamless learning have emerged, stemming from various diversified perspectives.

This book provides one snapshot of this latest state of research and development on seamless learning. The authors of the chapters include learning scientists and educational technologists who have been explicitly or implicitly researching seamless learning. These chapters report on recent work on the theorization of seamless learning as well as the conditions, resources, and frameworks for understanding such learning and probe their relevance and connections of seamless learning.

Part "Theoretical Niches and Frameworks for Seamless Learning" discusses theoretical frameworks and perspectives for seamless learning. Chapter 1 on "The Conceptual Niche of Seamless Learning: An Invitation to Dialogue" addresses the conceptual niche of seamless learning. By articulating the commonalities and differences with other learning notions, the chapter elucidates some conceptual and theoretical foundations of seamless learning. This creates an invitation to explore such "seams" between related learning approaches and notions in order to remove or to blur these "seams" for accomplishing more productive research by working together with researchers of these different perspectives.

Chapter 2 on "The Learning Problems behind the Seams in Seamless Learning" asks and probes the critical question of what does link or bridging contexts in seamless learning mean. It elucidates the differences in the nature and experiences of learning in different contexts, modalities and outcomes of learning, and the consequences of context switching for the learners' experiences. This chapter makes an important contribution to the theorization of seamless learning, and to the framing of the design principles for seamless learning.

Chapter 3 on "External Representations and the Design of Seamless Learning Systems" examines seamless learning from the perspectives of external representations. Through applications of such perspectives to seamless learning design and research, it provides a theoretical foundation for supporting the design, development, and evaluation of future systems with seamless learning in mind.

Chapter 4 on "An Inspiration from Border Crossing: Principle of Boundary Activity for Integrating Learning in the Formal and Informal Spaces" uses the concept of boundary objects and crossing to analyze and design boundary activities for integrating learning in the formal spaces with informal learning spaces. It illustrates the application of this principle to the design of a seamless learning activity in primary school science.

The next part "Architectures and Technologies for Supporting Seamless Learning" has two chapters. Chapter 5 on "Towards an Architectural Approach to Supporting Collaborative Seamless Learning Experiences" probes the issues related to software architecture and implementing them into tools that support seamless learning. It proposes a candidate architecture for supporting three learning activities in the domains of usability, environmental studies, and computer science.

Chapter 6 on "Crossing over Settings, Practices and Experiences: Connecting Learning in Museums and Classrooms" emphasizes the pedagogies and processes that enable learning to occur across contexts. It describes a study that employs Twitter to support a series of blended lessons happening in learning spaces that include the classroom, the Museum of London, and beyond.

Part "Expositions and Experimentations of Seamless Learning" shares designs and empirical work on seamless learning. Chapter 7 on "Sensors for Seamless Learning" explores the roles of sensors and augmented reality applications for providing contextual information for supporting seamless learning experiences. The conceptual model of AIChE is used as a framework for designing AR applications for seamless learning which enable embedding feedback and guidance in augmented displays.

Chapter 8 on "Designing Seamless Learning Activities for School Visitors in the Context of Fab Lab Oulu" shares the seamless learning design for learning computational thinking and twenty-first-century skills in the context of a Fab Lab. It develops a pedagogical framework for seamless learning for Fab Lab activities based on multiple levels of interactivity that are enabled by different tools, activities, and contexts.

Chapter 9 on "Supporting Seamless Learning with a Learning Analytics Approach" explores a learning analytics approach for the implementation of a seamless learning environment. It describes and evaluates a system that visualizes and analyzes learning logs in order to bridge between online learning with e-books and real-life learning.

Chapter 10 on "Seamless Writing: How the Digitisation of Writing Transforms Thinking, Communication, and Student Learning" extends the scope of seamless learning toward text writing. Seamlessness in writing refers to coherence in the practice and learning of writing, with seams being interpreted as frictions or barriers in the writer's experiences. The chapter presents a system called Thesis Writer to exemplify such a seamless writing environment. The chapter raises the thought-provoking notion that removing seams from a learning environment may incidentally introduce new seams.

This book extends our understanding of seamless learning by including different strands and aspects of research and practice. The chapters included show the commonalities as well as the differences among theoretical, technical, and practical perspectives on this educational field. This book will have served its purpose if it informs further research, theory, and practice on seamless learning by stimulating the awareness of wanted and unwanted seams in designing and implementing processes and resources for education and learning.

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Part I
Theoretical Niches and Frameworks for Seamless Learning

Chapter 1
The Conceptual Niche of Seamless Learning: An Invitation to Dialogue

Lung-Hsiang Wong and Chee-Kit Looi

1 Introduction

Over the last few decades, the rise of the student-centred learning movement has rendered a flurry of relevant learning or pedagogical approaches being developed, most of which are underpinned by the sociocultural or cognitivist perspective of learning. Some approaches went on to gain momentum and popularity in both the academic and practical sectors; a few even reached a critical mass to launch their specialised annual conferences and journals. Others have remained in their own niche communities or have relatively low numbers in terms of publications. Seamless learning is one such emerging learning notion that seems to be situated in between the two above-stated statuses, twelve years after it was inducted into the mobile and ubiquitous learning field.

First proposed in the field of higher education studies that advocate systemic reforms in the US colleges by binding together students' academic and non-academic experiences (American College Personnel Association, 1994; Kuh, 1996), and it was later appropriated as the key techno-pedagogical approach underpinned by G1:1, the global community with the aim of promoting research in technology-enhanced learning in 1:1 (one-or-more-device-per-learner) settings (Chan et al., 2006). This 2006 definition is motivated by a new phase in the evolution of technology-enhanced learning, characterised by "seamless learning spaces" and marked by continuity of the learning experience across different scenarios or contexts, and emerging from the availability of one device or more per student ("one-to-one") (Chan et al., 2006). The definition in 2015 views seamless learning as "… when a person experiences a continuity of learning, and consciously bridges the multifaceted learning efforts, across a combination of locations, times, technologies or social settings." (Wong, 2015, p. 10; adapted from: Sharples et al., 2012). Thus, the more recent definitions

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provide an expansive view that goes beyond 1:1 settings and with seamlessness across more multi-dimensions.

Since 2006, the core members of G1:1 spearheaded a series of seamless learning research studies to frame and make better sense of the new (or renewed) learning notion (e.g., Deng, Lin, Kinshuk, & Chan, 2006). Some have developed point-at-able techno-pedagogical models (e.g., Looi et al., 2010). A few other intervention studies were originally rooted in alternative theoretical frameworks and yet the researchers retrospectively associated their techno-pedagogical designs with seamless learning (e.g., Kurti, Spikol, & Milrad, 2008; Maldonado & Pea, 2010; Underwood, Luckin, & Winters, 2010). Since the initial enthusiasm in the G1:1 community, many key members have shifted their research interests to other areas. Subsequently, other researchers took over the baton by making contribution in developing new characterisation or pedagogical frameworks (e.g., Nicholas & Ng, 2015; Uosaki, Ogata, Li, Hou, & Mouri, 2013; Wong & Looi, 2011), research methods (e.g., Toh, So, Seow, Chen, & Looi, 2013; Wong, Chen, & Jan, 2012) and technological environments (e.g., Ogata et al., 2014; Tissenbaum & Slotta, 2015; Zurita & Baloian, 2015) to advance the scholarly understanding and achieve practicality in seamless learning. There were also occasional synthesis efforts such as a special issue on "Seamless, Ubiquitous, and Contextual Learning" in the IEEE Transactions on Learning Technologies (Looi, Wong, & Milrad, 2015) and edited books specialised in technology-enhanced seamless learning (Şad & Ebner, 2017; Wong, Milrad, & Specht, 2015).

As scholars continue to struggle in developing seamless learning into an established learning notion or further spread the practices in formal school settings or in adult learning, the learning notion is still under-theorised to date. The cross-temporal and cross-spatial nature of seamless learning has been posing methodological challenges to researchers, and design, implementation and evaluation challenges to practitioners, as well as self-regulating and cognitive challenges to learners. Even keen adopters might be plagued by curricular rigidity or the lack of technological infrastructure readiness. Thus, beyond the current seamless learning research and expositions, the learning notion may remain obscure to most scholars and educators—even within the mobile learning field.

In the occasions where seamless learning is introduced to a first-time listener, the latter tends to associate the learning approach with similar and more established learning notions that one is familiar with—such as blended learning, self-regulated learning, and lifelong learning. The question now is that whether seamless learning is just a special form of some other learning notion (or any other technology-enhanced learning paradigm—such as that seamless learning had historically been touted as a special form of mobile and ubiquitous learning), or a learning approach at its own right and with its own niche?

Henceforth, this book chapter is intended to be an inquiry on the uniqueness of seamless learning. This will be done by comparing the salient characteristics of seamless learning with the definitions and framing of other relevant learning notions or approaches. Notwithstanding, the endeavour does not treat other learning notions as competing solutions and is not meant for evaluating which solution is better than which. Rather, the intention is to make sense of the similarities and differences of these learning notions. It is hoped that the new-found understanding will inform cross-fertilisation between seamless learning and other learning notions to inspire and guide the advancement of the relevant research and practice.

Seamless learning has the potential to become a "meta-learning approach" that spans, encapsulates or extend the currently known learning designs. Being a meta-learning approach means that there are sub-approaches, thereby creating some confusion with similar (sub) approaches. This is in the same sense of design-based research being a meta-methodology, therefore overlapping with other sub-methodological approaches.

2 The Key Concept and the Theoretical Basis of Seamless Learning

The intent of seamless learning is to remove the seams so as to enable learners to learn whenever they are curious and seamlessly switching between different contexts, such as between formal and informal contexts and between individual and social learning, and by extending the social spaces in which learners interact with each other. A theoretical basis is needed to explain how the mechanisms and processes behind seamless learning lead to explanations of how learning occurs.

In the literature, researchers have studied cognitive learning processes and theorisations behind each of the seamless learning spaces, such as learning individually, in the group, online learning, face-to-face learning, and through the construction of artefacts mediated by technology. Different affordances in the physical space or virtual space or over time lead to different episodes of learning experiences, each of which may be grounded in some theorisation of learning. However, a theorisation of seamless learning requires a meta-theory, more than an aggregate collection of disparate theories specific to each of the learning spaces.

Thus, the unit of analysis should be the integrated continuous learning processes. In seamed learning, episodes of learning are separated by the seams. The design of learning in online learning is distinguished from the design of learning in the face-to-face settings. Even if both designs are considered together, the linkages may not be brought to the fore in the design. In the seam between individual learning and social learning, theorisation from the computer-supported collaborative learning (CSCL) community takes the form of the transitions of learning via individual cognition versus group cognition.

A key design consideration in seamless learning is to consider and design for removing the seams or planning for the linkages first, that is, planning for the continuous learning at the outset, before elaborating the design in the separate learning spaces. Seamless learning has been explained by the contextualisation or recontextualisation (Wong, Chai, Aw, & King, 2015) of learning. In formal settings, knowledge and skills may be taught in the abstract. The more contexts or settings in which learning a concept or skill takes place, the more powerful is the learning. Context refers to the different situations in which a concept or phenomenon is situated and interpreted. Removing or crossing seams would provide more opportunities for such contextualisation and recontextualisation. In doing so, the thinking and doing practices of learners are drawn to approximate those from the community of practices.

The crossover objects, or the boundary objects in the transitions between these learning spaces, in the form of artefacts, emerge, change and evolve as learners collaborate with peers, teachers and experts or conduct discovery, they acquire and build knowledge.

Seamless learning has been interpreted from a distributed cognition perspective. In the distributed cognition theory proposed by Hollan, Hutchins, and Kirsch (2002), they proposed three principles in which cognitive processes occur: they are distributed across the members of the social group; over time; and the operation of a cognitive system involves coordination between internal and external (material or environmental) structure. Applying these principles to seamless learning, learning takes place through individual learning in private learning spaces, collaborative learning in public learning spaces, and cognitive artefacts created across time and physical or virtual spaces mediated by technology within a context. In our earlier work, we have proposed sets of design principles for enabling seamless learning that supports the cognitive and social processes of learners; and we have recently consolidated and streamlined them into five items, namely designing for connectivity of learning spaces, socio-constructivist inquiry learning, formative assessments with student artefacts, leveraging resources in informal settings and personalised and self-directed learning (Wong, Looi, & Goh, 2017).

3 The Relationships Between Seamless Learning and Other Relevant Learning Approaches

In this section, we make an attempt to "dialogue" with some of the "close neighbours", that is, other learning notions that are often perceived by scholars as being conceptually overlapping with seamless learning. These approaches are chosen based on our understanding and scan of the literature about similarities and alignments in the theorisation or practice-oriented aspects of the approach with seamless learning.

3.1 Blended Learning

In a blended learning course, both online and traditional classroom-based teaching methods are utilised to provide a more effective learning experience for the students (Singh, 2003; Thorne, 2003). Blended learning is any formal education program in which a student learns at least in part through online learning, with some element of student control over time, place, path, and/or pace.

Blended learning can happen at different levels, such as the activity, lesson, course, programme or institutional level (Graham, 2006). It refers to an instructional or organisational arrangement of learning that provides a combination of computer-mediated (online) and face-to-face (offline) learning activities. Blending may be driven by different considerations or a combination of them, such as pedagogical, logistical, time, resources and organisational considerations.

Seamless learning emphasises the crossing of seams, one of which is between online learning and physical learning, to provide the continuity of the learning experiences and the contextualisation and recontextualisation of learning. Thus, it stresses the complementarity of the learning experiences in the different spaces, a principle which may or may not be advocated in the instructional design of blended learning. Researchers from seamless learning have argued for learning across the seams, as exemplified by theorisations of the distributed cognition framework (Otero et al., 2011; Seow, Zhang, Chen, Looi, & Tan, 2009; Wong et al., 2012). However, in blended learning, learning is within or by the seams, with bridging across the seams not foregrounded as learning mechanisms unlike seamless learning.

In self-directed seamless learning, the advocacy is for learners to be self-directed in creating their own continuity of learning experiences, and not as planned or scripted learning episodes as is the case in blended learning.

3.2 Self-Directed Learning (SDL)/Self-Regulated Learning (SRL)

The terms self-directed learning (SDL) and self-regulated learning (SRL) have often been used interchangeably over the past decades. Even their seminal definitions bear a strong resemblance. SDL "describes a process in which individuals take the initiative, with or without the assistance of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes" (Knowles, 1975, p. 18). On the other hand, "a general working definition of SRL is that it is an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behaviour, guided and constrained by their goals and the contextual features in the environment" (Pintrich, 2000, p. 453).

Despite bearing the obvious commonality, these learning notions belong to two different academic camps which are both instigated in the late 1960s. SDL was originated from the field of adult education outside the mainstream schooling system, while SRL was developed within the field of educational psychology and has been largely studied within K-12 school settings with a greater emphasis on correlating learner autonomy with academic achievements (Loyens, Magda, & Rikers, 2008).

Early SDL research focused primarily on definition and identification of self-directed learner's characteristics (Knowles, 1975). In later decades, cognisant that self-direction is best viewed as a continuum, new research trends emerged since 1990s where scholars began to study the actual practice of SDL (e.g., Boyer, Artis, Solomon, & Fleming, 2012; Grow, 1991, 1994). In addition, SDL was no longer considered unique to adults but also received some attention in K-12 settings (e.g., Areglado, 1996; Birenbaum, 2002; Van Deur & Murray-Harvey, 2005).

The SRL research, on the contrary, is rooted in cognitive psychology (Cosnefroy & Carré, 2014). Related studies predominantly come with the intentions of developing and validating psychological and metacognitive models of SRL (e.g., Boekaerts, 1988; Efklides, 2011; Järvelä & Hadwin, 2013; Pintrich, 2000; Winne & Hadwin, 1998; Zimmerman, 1989). These models anchor crucial variables that affect learning and at the same time explain their interactions (Panadero, 2017). Informed by such models, other SRL scholars have put in efforts to delineate SRL strategies, or develop and study the effects of SRL skill interventions (e.g., Dignath, Buettner, & Langfeldt, 2008; Hattie, Biggs, & Purdie, 1996).

An important difference between SDL and SRL which has raised our attention in the context of this chapter is that SDL constitutes a tool to examine learning episodes or specific courses as it allows looking at *learning actions* as indicators for SDL. SRL, on the contrary, is often happening on a metacognitive level and therefore is difficult to isolate purely based on self-reported data (De Waard, 2016).

In contrast with SDL and SRL, the notion of seamless learning essentially talks about a special form of *learning experience*—more specifically, continuity of the learning experiences across different scenarios or contexts, perhaps (not mandatorily) mediated by mobile and/or cloud technologies. The key concern of seamless learning researchers is "what it takes" to make seamless learning happens—and the evaluation focus has been on whether seamless learning *actions* do happen and what are their effects. Hence, on the surface, it seems that the original notion of seamless learning is more consonant with SDL than SRL.

Notwithstanding, according to Wong's (2015) critical analysis, there is a gradual shift of the academic foci from technology-enabling perspective (to develop technological infrastructure to facilitate seamless learning) to a pedagogical design perspective to the fostering of a seamless learning culture. The last perspective implies the need to unpack the motivational and metacognitive prerequisites of being a seamless learner. When seamless learning researchers began to reposition seamless learning as an aspiration (Sharples et al., 2012) or a habit-of-mind (Wong & Looi, 2011), rather than merely a persistent learning behaviour, they would recognise the necessity to incorporate cognitive psychological dimensions to advance seamless learning research. Thus, there is potential for prior research on SDL or SRL to assist the seamless learning community in filling the research gaps.

3.3 Lifelong Learning (LLL) and Heutagogy

From Harper Collins Dictionary, lifelong learning (LLL) is "the provision or use of both formal and informal learning opportunities throughout people's lives in order to foster the continuous development and improvement of the knowledge and skills needed for employment and personal fulfilment". London (2011) sees LLL as "a dynamic process that varies depending on individual skills and motivation for self-regulated, generative learning and life events that impose challenges that sometimes demand incremental/adaptive change and other times require frame-breaking change and transformational learning" (p. 3). Whereas the LLL notion inherently encompasses learning taking place between "cradle" and "grave", the relevant research and practice have been focusing on post-K-16 learning, which comes in the forms of continuing education, workplace learning, older workers' or senior citizen learning (particularly for remediating age-related cognitive decline), intergenerational learning, and interest-driven learning, among others. The key is to empower people to self-determine and self-manage their learning across time and contexts throughout their lifetimes (Bentley, 1998).

More recent literature has been associating LLL with heutagogy (Hase & Kenyon, 2000), a form of self-determined learning which is an extension of andragogy (Knowles, 1970). Luckin et al. (2008) put forward a pedagogy–andragogy–heutagogy (PAH) continuum. In a nutshell, pedagogy refers to K-12 education with instructors determining both the learning goals and approaches for the learners; andragogy refers to tertiary or adult education with instructors setting the goals while the learners are given free hand to choose their approaches; heutagogy means letting the learners decide on both. Luckin et al. (2008) further postulated that the cognition levels of pedagogy, andragogy and heutagogy are "cognitive", "metacognitive" and "epistemic", respectively. Bringing these three learning notions together as a continuum implies a developmental view of learning dispositions and skills.

In a related note, Kenyon and Hase (2001) incorporated double-loop learning (Argyris & Schon, 1978) as a key strategy for implementing heutagogy. What is opposite to double-loop learning is adaptive learning (see Fig. 1). Typically practised within pedagogical and andragogical settings, adaptive learning emphasises on primarily maintaining and repeating existing learning goals and learning approaches (i.e., the "single loop"); adaptation and improvements can be made, based on the track record of learning outcomes. Double-loop learning (also known as generative learning), on the contrary, requires learners to reflect upon and reorient or reshape their learning goals and strategies.

Thus, whereas andragogy is an extended form of structured formal learning, the notion of heutagogy places a greater emphasis on informal learning and learners' self-determination. Some of the salient characteristics of heutagogy are (1) learning how to learn; (2) double-loop learning; (3) leveraging opportunities of incidental learning in one's day-to-day life; (4) nonlinear trajectories of learning; (5) genuine self-directed learning (Hase & Kenyon, 2000; Wong & Chin, 2014).

Indeed, the framings of both LLL and heutagogy are eminently akin to seamless learning. Relevant research in LLL and heutagogy would inform post-college adult seamless learning, a relatively understudied area within the seamless learning field. Nonetheless, whereas the foci of the research in LLL and heutagogy are placed on self-determination and persistence in learning across time, the seamless learning scholars are showing their greater interest in cross-contextual flow of learning. Thus,

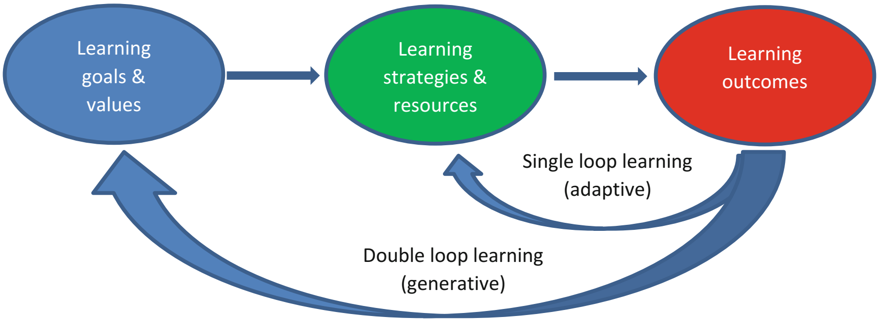

Fig. 1 Single- and double-loop learning

as compared to LLL and heutagogy, the seamless learning field tends to facilitate, study and unpack learning in finer granularity. Notwithstanding, the notion of double-loop learning may imbue seamless learners to consciously look back and cogitate about their previous learning endeavours—a key metacognitive disposition for seamless learning.

3.4 Crossover Learning

The term "crossover learning" was loosely referred to in scattered educational research literature since 1990s (e.g., Appleby & Hamilton, 2005; Bedore, 1992; Edwards, 2008). It was not until 2015 when the annual Innovating Pedagogy Report (Sharples et al., 2015) featured a section that demarcated the learning notion. However, as the report was targeting policymakers and practitioners, the writing was not intended to be an academic treatment to or a theorisation effort on the notion. Thus, "crossover learning" has not yet been developed into a research niche. Instead, it can be regarded as a new practical advocate. Still, it is interesting to examine the relationship between the notion and seamless learning.

According to the above-stated report section, crossover learning refers to "the ways we can connect formal and informal learning experiences, benefiting from the crossover between them" (Sharples et al., 2015, p. 11). Furthermore, the section foregrounds "learning ecosystem" that sees diverse settings and contexts with latent learning opportunities as one. The key exposition of the section is placing on the roles informal and non-academic learning could play in both supplementing learners' pursuance of academic goals and development of traits and skills such as persistence and self-direction. Thus, crossover learning should move towards a competency-based approach rather than on the volume of knowledge gained.

Technology could play an important part in accomplishing crossover learning. The examples raised in the section are using digital badges to track and recognise less formal achievements, and employing social media platforms that allow learners to gather data/resources and develop transferable skills such as curation, evidence building and reflective commenting.

Panke (2017) extended the explication of crossover learning, though apparently with a focus on the contexts of adult, workplace or professional learning. In the online article, she relates the informal learning components of crossover learning to communities of practice, personal networks, and work-related tasks. Her conceptualisation is congruent with connectivism that sees knowledge as distributed across an information network. However, the renewed explication seems to depart from the "original" framing made by Sharples et al. (2015) as the roles of formal learning are omitted in the article.

Given the above expositions, we argue that crossover learning can be seen as a specific conception of seamless learning. Sharples and colleagues' (2015) exposition focuses on only one dimension of seamless learning, namely connecting formal and informal learning—though it may implicitly encompass the rest of the dimensions derived by Wong and Looi (2011), such as connecting individual–social settings and physical–digital learning realms. Panke's (2017) exposition has instead placed the emphasis on connecting individual–social settings. Building a learning ecology that incorporates multiple learning settings is a common advocate of both learning notions (see: Ng & Nicholas, 2013; Seow, So, Looi, Lim, & Wong, 2008; Song, 2013) and yet further unpacking is needed. There were also attempts of designing seamless learning environments that make use of social media (e.g., Charitonos, Blake, Scanlon, & Jones, 2012; Laru & Järvelä, 2015; So, Seow, & Looi, 2009; Wong, King, Chai, & Liu, 2016) or digital badges (e.g., Boticki, Baksa, Seow, & Looi, 2015) for similar purposes. In particular, Wong, Chai, and Aw (2017) proposed the SMILLA (Social Media as Language Learning Artefacts) Framework that details a theory-rooted mechanism to appropriate social media for both learner community building and language learning purposes—and there is a potential for this framework to be adapted for other subjects, cross-subject or even interest(-group)-driven learning.

3.5 Long-Tail Learning

The phrase "The Long Tail" was first coined by Chris Anderson in an October 2004 Wired magazine article to describe how our culture and economy is increasingly shifting away from a focus on a relatively small number of "hits" (mainstream products and markets) at the head of the demand curve towards a huge number of niches in the tail. This is exemplified by companies such as Amazon or Netflix, that sell a large number of unique items in relatively small quantities (Brown & Adler, 2008).

Long-tail learning comprises at least two facets: (1) learning about exotic topics outside the formal curriculum and (2) the opportunity to communicate with people who share similar niche interests somewhere in the world on a regular basis (Collins, Fischer, Barron, Liu, & Spada, 2009). Long-tail Learning overlaps much with informal learning as learners pursue the opportunity to learn, share and teach at the same time and justify the basis of both (individuals') passion-based, self-motivated learning (Domik & Fischer, 2011) and collaborative learning.

Collins et al. (2009) further discussed how the Web technology may afford the two aforementioned facets of long-tail learning. On the one hand, the Web is both constantly evolving and actively filling up all the long tails of knowledge about every conceivable topic, it can support individual learners' long-tail (passion-based) learning in a way not even the largest physical library in the world can support. On the other hand, the participatory Web 2.0 provides unique possibilities for an educational interpretation of the "Long Tail", thereby creating new feasibility spaces for collaborative learning.

Long-tail learning may be seen as a learning notion that is biased towards participatory learning, given that most of its earliest explications since Chris Anderson's 2004 article was published (Collins et al., 2009; Karrer, 2008; Tynan & Colbran, 2006) had been foregrounding the roles of Web 2.0-enabled learning communities on niche topics. Nevertheless, subsequent relevant literature has instead promulgated the learning notion's consonance with one of the key dimensions of seamless learning—bridging individual and social learning. The establishment of a long-tail learning community must begin with individuals' passion and self-determination in pursuing the relevant topic. Decision-making about connections (with online resources and with a relevant online community) becomes critical in long tail of learning (Klamma, 2010). Novice learners may lurk in long-tail communities to glean relevant ideas and skills for self-enrichment. When learners develop expertise, they can share their (completed or work-in-progress) artefacts or their thoughts to the community and gain feedback to guide their further development. In this sense, individual and social learning are reciprocal.

Du, Wang, Du, and Feng (2012) further unpacked the conceptualisation in the previous paragraph by characterising individual learning as constructivist learning, and social learning as connectionist learning. "A person is no longer able to have all necessary knowledge personally, who has to store it in others or technology" (Du et al., 2012, p. 495). The knowledge formed after constructing is in the head, while the large amount of information is in tail which mainly depends on the connection. Thus, Du et al. (2012) considered long-tail learning as an integration of three kinds of nets—neural networks (self-learning), Internet (online resources) and social networks (either online or real-life learning communities).

In this regard, we see a great potential in the long-tail learning notion in inspiring seamless learning researchers to study the underlying cognitive or sociocultural mechanism of bridging individual and social learning. Cognisant with Du et al.'s (2012) explication, we believe that a learner cannot simply "construct" but not "connect", and neither vice versa.

3.6 Wildfire Activities

Engeström (2004, 2009) put forward the notion of wildfire activities about 15 years ago. He envisioned a form of learning in a decentralised manner, with emerging communities of social or peer production activities across the time and boundaries.

One of the examples he cited was birding (Law & Lynch, 1988), where birders are swarming punctuated by bird movements. They document their sightings and share them through various channels such as social media to fellow bird lovers. Subsequently, they comment on each other's sightings and views and therefore elicit knowledge improvement and perhaps subsequent bird watching activities at the same or other potential sighting locations. Thus, in general sense, wildfire activities are transient in nature, appear or disappear unexpectedly or flare up and expand and may be temporarily extinguished but later reappear.

Apparently, wildfire activities are interest- or hobby-driven in nature, as Engeström (2009) posited that these activities show remarkable sustainability and expansion where the actors (learners) are constantly learning to overcome the constraints and hindrances, often without much centralised effort. According to him, "Transformative learning is not imposed upon the participants, but built into the very operating principles and everyday social textures of these activities" (2009, p. 5).

Two key concepts of wildfire activities are trail and stabilisation. People move around in territories and leave trails, i.e., markings of the environment. In the era of Web 2.0, the trails left by people may come in the form of social media postings pertaining to their experiences in interacting with the environment along their experiential/learning journeys. When multiple trails are marked by different actors (or learners), it forms a network of cognitive trails. The trails are then "stabilised" by the actors through "the imposition of linguistic structure on experiential structure"—which means that the actors learn by (co-)constructing collective concepts that "stabilise" the trails, which may trigger restructuring of the subsequent activities. For example, upon encountering geo-tagged user-generated content while visiting a location, a visitor would feel inspired to offer their response or contribute a new item for someone else to stumble upon in the future (FitzGerald, 2012). Thus, such trails are both material, "in the world", and cognitive, "in the mind" (and being stabilised through generating and improving shareable representations of the trails) (Cussins, 1992).

Engestrom's exposition on wildfire activities may constitute a theoretical basis of a special form of seamless learning, which is situated in the informal end of the formal–informal learning spectrum, and relies heavily on social bonds in informal, largely unstructured but self-organising communities of actors/learners with similar interests, with a key focus on peer production activities. Several techno-pedagogical designs as reported in prior seamless learning literature bear a strong resemblance with such peer production activities, including the highly informal learning-oriented designs (e.g., Charitonos et al., 2012; Ogata et al., 2014; Underwood et al., 2010), or formal learning-driven but with a strong emphasis on student artefact generation activities in informal learning contexts (e.g., Anastopoulou et al., 2012; So et al., 2009; Wong, 2013; Wong et al., 2016).

In particular, from the perspective of seamless learning, the acts of "recording" and stabilisation the trails (i.e., the generation of user/learner artefacts) become the crucial means of mediating and bridging subsequent learning activities, and connecting individual and social learning. Making "bridging" happening is indeed what it takes to invoke, sustain and expand seamless learning—and even "propagate" seamless learning to fellow learners.

3.7 Free-Choice Learning

As its name suggests, free-choice learning is a learning advocate where the learner is given a large degree of freedom in determining when, where, what, why and how to learn. Falk and Dierking (1998) defined free-choice learning as voluntary, self-paced, non-sequential and reflecting learner-perceived choice and control. According to this notion, learning is conceptualised as a cumulative process of the interactions among an individual's ever-changing personal, sociocultural and physical contexts across her/his lifetime. As an effort of unpacking the contextual conditions of free-choice learning experiences, Falk and Dierking (2000, 2004) proposed the contextual model of learning, which encompasses aforementioned contexts with sets of factors under each context,

- Personal context: with the factors of (1) visit motivation and expectations; (2) prior knowledge; (3) prior experiences; (4) prior interests; (5) choice and control.
- Sociocultural context: with the factors of (6) within group social mediation; (7) mediation by others outside the immediate social group.
- Physical context: with the factors of (8) advance organisers; (9) orientation to the physical space; (10) architecture and large-scale environment; (11) design and exposure to exhibits and programs; (12) subsequent reinforcing events and experiences outside the physical space.

The conceptualisation of learning among seamless learning researchers, in particular the concepts of "bridging" and "recontextualisaion", indeed strongly resembles Falk and Dierking's (2000), who argued that "people do not learn things in one moment in time, but over time" (p. 10), and "learning is constructed over time; as the individual moves within his or her sociocultural and physical world … meaning is built up, layer upon layer" (p. 11).

While the notion sounds like yet another variation of (personal or individual) autonomous learning that privileges informal learning, research in free-choice learning has instead been traditionally emphasised on studying groups of learners' perceptions on their episodic visits to non-formal learning settings such as museums, science centres, zoos and botanical gardens (e.g., Tofield, Coll, Vyle, & Bolstad, 2003; Yang & Chen, 2015), or their learning behaviours during the visits (e.g., Bamberger & Tal, 2006; Mortensen & Smart, 2007). Thus, the relevant studies and the implications or recommendations arisen from those seem to be more site—(e.g., how museum learning should be redesigned or reformed) than individual learner-oriented. Furthermore, the potential roles of ICT in facilitating free-choice learning are hardly investigated in free-choice learning research—recent exceptions are explorations of mobile and wireless technologies for in situ free-choice learning (Aguayo & Eames, 2017; Tesoriero, Fardoun, Awada, & Raisinghani, 2018).

Conversely, the research in seamless learning has been more holistic—with studies in both pedagogical (e.g., curricular designs adhering to the notion of facilitated seamless learning (Song, 2014; Wong & Looi, 2018)) and cultural (e.g., case studies on individual seamless learners (Panke, Kohls, & Gaise, 2017; Toh, So, Seow, & Chen, 2017)) perspectives being conducted.

3.8 Third Space Learning

Various earlier publications on education and learning (e.g., Brooke et al., 2005; McLaughlin & Mills, 2008; Skerrett, 2010) coined the term "third space" to describe the learning space where the first (formal school settings) and the second (where informal learning may take place—museums, parks, home, etc.) spaces intersect. Gutiérrez (2008) further postulated third space as a discursive construct involving conversations and interactions among teachers and students during the learning process. Thus, despite of nuances in the positionings among various literature, the term "third spaces" typically refers to social learning settings beyond classroom, either online or physical, to bridge the students' formal and informal learning endeavours.

Lately, Schuck, Kearney and Burden (2017) seek to "build on and expand on this notion of using mobile technologies to support "seamless learning" with the construct of m-learning in the Third Space" (p. 125). They defined the third space as "an emergent shared space, providing an opportunity to develop contemporary learning skills and knowledges, a space that extends beyond traditional, institutional learning with rigid, temporal schedules to also include the spaces of more spontaneous, often incidental learning, unconstrained by classroom walls and set schedules, and sometimes free from teachers and prescribed curricula" (p. 123). The new definition foregrounds extending (not excluding) curriculum-driven activities to learning in informal settings or student-initiated informal learning. The definition seems to depart from the earlier conceptualisation which was social learning-focused—though the key characterisation of the third space is that it is "an emergent shared space", which implies potential social interactions and negotiation of meanings. Notwithstanding, the new conceptualisation seems to see the formal, third and informal spaces as three discrete learning spaces (i.e., an extension of the traditional dichotomous view of formal and informal spaces), which differs from the formal–informal continuum view of seamless learning (Wong & Looi, 2011).

Unlike the more recent reconceptualisation of seamless learning that sees it as a learning notion on its own, with or without (or: in and out of) technological supports Wong (2015), Schuck et al. (2017) considered mobile technologies as the key enabler of third space learning. The technologies afford and mediate the flow of learning, information, ideas and concepts among contexts, resulting in boundary crossing. In addition, Schuck et al. (2017) embraced the notion of learner-generated spaces (as a special form of third space) and called for "recognising opportunities for and even anticipating contexts that may elicit incidental, spontaneous learning interactions; and also planning for pre- and post-episodic asynchronous learning conversations" (p. 128)—an advocate that echoes Wong (2013) and Wong, Chen, and Jan's (2012) postulation of learner-generated contexts within seamless learning settings.

4 Well-Known Learning Approaches Go Seamless

Apart from dialoguing with the conceptual "neighbours", another potentially inspirational aspect on the advancement of seamless learning is to review how seamless learning has been applied to or hybridising with extant learning approaches. The studies in seamless learning in the past decade have manifested the versatility of the learning notion in adapting otherwise predominantly single-context learning designs for greater holisticality and flexibility. In this section, we will focus on examining the mechanisms, the values and (if any) the caveats of such "seamless-ised" learning designs as reported in the existing literature.

4.1 Seamless Flipped Learning

Teaching professionals often have difficulty in distinguishing blended learning, flipped classrooms and flipped learning, as all of them are learning approaches that involve both online and face-to-face learning activities. According to Pappas (2016), in blended learning, both the technology and face-to-face instruction are used alongside and complement each other (e.g., online materials do not take the place of face-to-face instruction); in flipped classroom or flipped learning, there is a clear divide between the technology and face-to-face elements of the learning experience. In particular, in the "orthodox" sense of flipped classrooms (see Bergmann & Sams, 2012), a learner is asked to watch the teacher's video-recorded lecture possibly accompanied with other learning materials before coming to class. That saves the time for in-class content delivery and the teacher may instead facilitate student discussions or practice to apply the knowledge or clarify misconceptions.

Flipped learning constitutes a more sophisticated view of flipped classrooms where the four pillars of F-L-I-P must be incorporated (flexible environment, learning culture, intentional content, professional educator). In particular, the "F" refers to educators' incorporation of a variety of learning modes, rearrangement of physical learning spaces that support either group or independent studies, and accommodation of students' choices of where and when to learn.

Building on the renewed conceptualisation, Hwang, Lai, and Wang (2015) developed a mobile-assisted seamless flipped learning model that makes use of mobile and wireless communication technologies to seamlessly connect learning activities at home, in-class and in-field (Fig. 2). In this model, Hwang et al. (2015) proposed various activity types either taking place within a single context (e.g., in-class peer assessment) or across two contexts (e.g., problem-based learning across the classroom and the field, or issue-quest learning across the classroom and home).

Thus, the seamless flipped learning model (and perhaps flipped learning in general, given its requirement of "flexible environment") marks a significant departure from how the original flipped classroom approach was intended and specified. The original flipped classroom approach bears the nature of teacher-designed learning

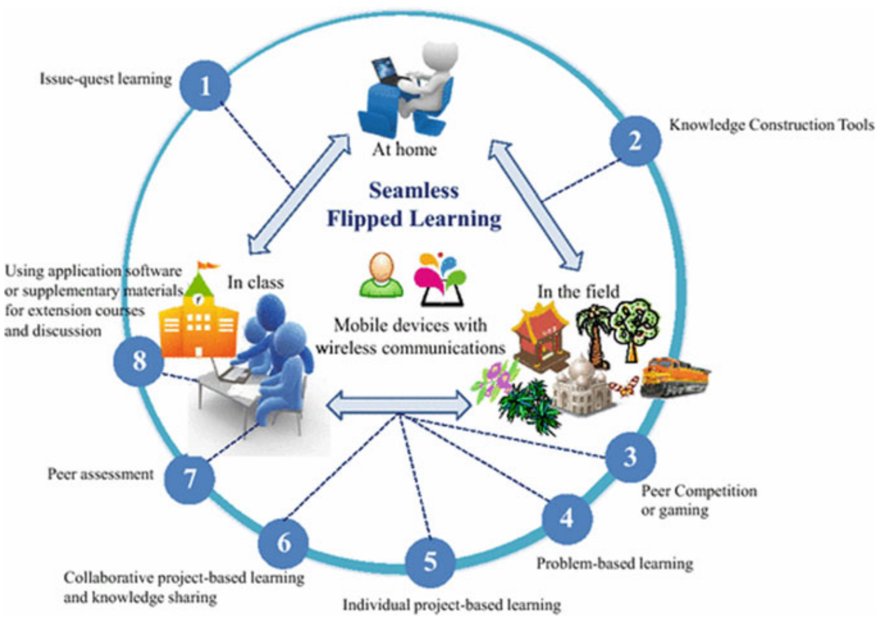

Fig. 2 Seamless flipped learning (*Source* Hwang et al., 2015, p. 456)

trajectory throughout—including the classroom activities which are supposedly student-centred and yet must be designed and facilitated by the teacher (blended learning bears a similar nature). On the contrary, seamless flipped learning allows out-of-school emergent, apart from planned learning. Furthermore, seamless flipped learning advocates the use of technologies across all settings, which defies the flipped classroom prescription of “clear divide between technology and face-to-face elements of the learning experience”. Thus, in a sense, seamless flipped learning is conceptually “big seamless” but “small flipped”. On the other hand, the model is perhaps a demonstration of how flipped learning may be subsumed into the designs seamless learning journeys, or how the more generic, flexible notion of seamless learning may enrich a flipped learning design.

4.2 Seamless Knowledge Building

Some technology-enhanced learning literature has been using the term “knowledge building” loosely in characterising the general constructivist learning activities involved in the reported techno-pedagogical designs. Instead, the notion of knowledge building (KB) developed by Scardamalia and Bereiter (Scardamalia & Bereiter, 2006) refers to the creation, testing and improvement of conceptual artefacts (or “ideas”) (Bereiter & Scardamalia, 2003) within a community of learners. What distinguishes KB from other constructivist pedagogies is the creation of original, progressive public knowledge, with an "out-in-the-world" character (Burden, 2017). A "genuine" KB learning environment should uphold a Popperian epistemology, namely ideas are improvable by means of a public discourse of scrutiny, testing and modification (Popper, 1972) and implement most of the twelve principles of KB identified by Scardamalia (2002).

Activities within a KB community may either take place solely on online forums, or switch between in-class and online interactions. The latter setting is particularly demonstrating a seamless learning-like element with the bridging of face-to-face and computer-mediated communication (CMC) contexts being ensued. From the perspective of seamless learning, both contexts provide overlapping yet distinct affordances to advance the community's knowledge building "journey" in different ways. For example, Van Aalst and Chan (2012) argued that Knowledge Forum provides a more "seamless knowledge-building environment" (p. 101), which makes linkages between online and offline (in-class) discourse less artificial.

So, Tan and Tay (2012) presented a study that brought together mobile-assisted outdoor learning trails and ongoing KB with on Knowledge Forum (before, during and after the trails). In their design, a majority of student ideas were arisen from the experiential learning activities on Sentosa Island, a tourist attraction in Singapore, for learning of integrated humanities, such as through interpretations of the photos taken, tourist interviews, calculation of gradient of slopes (i.e., to practice geographic and mathematical skills), design thinking of the attractions, accessibility and amenities of Sentosa. Indeed, KB includes the building of knowledge contexts; and such student-generated artefacts offer provisional contexts, which are triggers or bases of idea generation and rise above (Bachmair & Pachler, 2015). According to the analysis in a subsequent publication by the team (So & Tan, 2014), the overall learning experience was very much adhering to the KB principles and at the same time demonstrating the salient features of cross-contextual seamless learning.

4.3 Seamless Task-Based (Language) Learning

Task-based learning (TBL), Willis (1996) is a learning approach specifically for language education. It constitutes a reverse of the traditional language teaching sequence of PPP ((teacher's) Presentation—(student's) Practice—(student's) Production) by enacting meaning-making activities (or "meaningful tasks") *before* form-focused activities (reflecting on and fixing the grammar and vocabulary usage). Skehan (1996) defined tasks as activities which have meaning in their primary focus. The meaningful tasks could be role-playing, telling a story based on a picture, negotiating for a solution to a real-world problem, etc., that utilise the target language for communication.

Willis (1996) developed a framework that defines a three-stage activity sequence—pre-task (to prepare the students for the tasks and equip them with pre-requisite linguistic knowledge), task cycle and language focus. "Conventional" TBL lessons that encompass the aforementioned activity sequence are taking place within classroom. Thus, the authenticity of the tasks (a salient feature of TBL) is indeed "simulated". On the contrary, several mobile-assisted TBL projects have broken the physical and temporal seams that confine the students within classroom lessons and brought the tasks to genuinely authentic contexts. For example, the intervention designs in various studies (e.g., Anderson, Hwang, & Hsieh, 2008; Ogata et al., 2008) that adhere to the three-stage sequence require individual students to leave their classroom and communicate with native speakers in authentic environments such as asking the way, checking the train schedule, or bargaining with a street vendor. They then bring back the audio recordings of the conversations for in-class form-focused reflection activities. Other seamless language learning designs (e.g., Liu & Chen, 2015; Wong et al., 2016) tap on Web 2.0 by facilitating students to create social media pertaining to their day-to-day encounters. Such student artefacts are then constituting the basis for further peer activities including meaning-focused socialisation and form-focused evaluations with the reply feature of the social media. In this regard, Wong, Chai, and Aw (2015) developed a seamless language learning framework that was informed by both second-language acquisition theories and TBL to guide the designs of such language learning interventions.

5 Discussion and Conclusion

In our attempts to draw comparisons with known approaches, epistemic frameworks or theorisations of learning, in the space of a chapter, the descriptions and discussions of each of them will be necessarily brief. Thus, we run this risk of providing imprecise or incomplete renditions of such learning approaches or missing their nuances. We reiterate that it is not our intention to provide superficial comparisons nor be evaluative of other approaches. Really this is an invitation to dialogue to continue the discussion to seek conceptual clarity of each approach and to derive even more insightful understandings or new perspectives if we put similar approaches in juxtapositions with each other.

In articulating the essences of each learning approach and notion, and their interrelationships, we might be able to identify opportunities for further synergistic integration. For example, the synergy between wildfire activities and third space learning implies the need to develop/distil a generic design framework for "third space" in seamless learning. Existing sets of seamless learning design principles may provide some guidance, but there is no framework specifically for this purpose. Examples of third spaces in existing seamless learning environments include the social networking space in MyCLOUD (Wong et al., 2016) and miLexicon (Underwood et al., 2010), the Knowledge Forum for in situ KB activities (So & Tan, 2014), SCROLL (Ogata et al., 2011) and Personal Inquiry platform (Anastopoulou et al., 2012).

As another example, wildfire activities and long-tail learning are conceptually overlapping with their mutual interest in advocating and studying learners' reaching out to the niche (and typically self-organised without centralised control) community of people of the same learning areas to advance their own learning. Nonetheless, wildfire activities are well-theorised, placing a greater focus on situated learning and interacting with the living spaces, and introducing "trail" and "stabilisation" as alternative means of social learning. This is apart from explicit, intentional communication and sharing through social media contributions and discussions, in which certain seamless learning designs, have incorporated. The concepts of "trail" and "stabilisation" may also underpin the ant colony optimisation algorithms (Steels, 1991) in computer science in which the "roads" (learning pathways) more "travelled" by many learners, with good learning outcomes are identified and recommended to future learners (e.g., Pushpa, 2012; Rastegarmoghadam & Ziarati, 2017; Wong & Looi, 2009).

During the last fifty years, continuous educational and technological innovation has had profound effects on how learning is understood. Although we are trying to position seamless learning as a learning notion on its own, we must recognise that technology is a key stimulus for seamless learning to prevail. SDL, SRL and free-choice learning are learning notions/activities that are not necessarily involving technologies, but technologies are essentially playing an "enhancer" role. Blended learning and third space learning are very much the technology-driven learning notions; technology is essentially seen as "enablers". Wildfire activities and crossover learning lie somewhere in between the two types of notions in which technology has not only extended the existing learning spaces, but also afforded new learning spaces, or new layers of learning spaces to bridge existing learning spaces.

In this chapter, we also share three models of hybridising seamless learning with the approaches of flipped learning, knowledge-building and task-based language learning. Other "seamless-ised" learning approaches that were reported in the literature include seamless inquiry learning (e.g., Sharples et al., 2015; Song, 2014; Wong & Looi, 2018), seamless situated learning (e.g., Bozkurt, 2017; Zurita & Baloian, 2015), seamless experiential learning (e.g., Lai, Yang, Chen, Ho, & Chan, 2007; Song, Wong, & Looi, 2012), seamless learning in massive online open courses (MOOCs) (e.g., De Waard, Keskin, & Koutropoulos, 2014; Sharples, Delgado Kloos, Dimitriadis, Garlatti, & Specht, 2015) and seamless knowledge management underpinned by the SECI (Socialisation, Externalisation, Combination, Internalisation) model (Baloian & Zurita, 2012; Zhang & Maesako, 2009), among others.

The inclusion of seamless learning design principles brings in considerations of extending the spaces and time durations of such original learning designs. The arguments laid out in this chapter can point to seamless learning becoming a "meta-learning approach" that spans, encapsulates or extends the currently known learning approaches. From the perspective of operationalisation, we see such a meta-learning approach as a set of "heuristics", which comes in the form of seamless pedagogical design principles for guiding practitioners, or in the form of metacognitive skills for seamless learners to intentionally bridging their learning efforts across different contexts as well as self-identifying opportunities to learn within individual contexts.

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Chapter 2
The Learning Problems Behind the Seams in Seamless Learning

Bernadette Dilger, Luci Gommers and Christian Rapp

1 Introduction and Problem Statement

In the seamless learning literature, one main emphasis can be seen in the different settings and contexts in which learning takes place and on the possibilities to link or bridge them (Kuh, 1996; Wong, 2015). This highlights the potential to use resources from different domains in life, which helps us to move back and forth between experiencing and reflection. This results also from a steadily growing demand of mobility and flexibility. Increasingly, more technology is being integrated within the learning environment, which offers the potential to access more and different contexts and brings about new ways of bridging contexts. This is a consequence of the driving forces of digitalisation in the socio-technical and economic contexts. The promise behind seamless learning is enhanced learning; for instance, through learning, experiences can be made in more authentic contexts.

Thus, the possibilities and requirements to use more and different contexts for learning are increasing. However, learning in different contexts means that the risk for

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fragmentation of the learning process and the learning impact grows. Fragmentation of learning occurs since learning takes place in distinct context-based experiences and the learners themselves have to integrate the different learning experiences and outcomes in order to build and develop their own competence. We define competence as the integration of knowledge, skill, and attitude (Lizzio & Wilson, 2004).

Learners move across different contexts, which equally differ from the contexts others move within. Prior to the seamless learning approach, transition and integration processes of the individual learner have, until now, been kept implicit and not directly scaffolded. From a learning perspective, this leads us to question what this means for seamless learning processes and the design of seamless learning environments. Seamless learning provides a concept for bridging and integrating contexts. In the majority of literature in the seamless learning field, the problem of learning in different contexts is tackled by aligning contexts with each other. The seams are removed or at least mitigated by integrating elements from one context into the other (e.g., using the same technology in different contexts to transfer experiences from one context to another) (Chan, 2015; So, Kim, & Looi, 2008). Two former distinct contexts become one enlarged, integrated context. From our point of view, this can only work to a certain extent, since the possibilities of context integration are limited and differences between contexts naturally vary. If we take a radical look from the learners' perspective, we have to thoroughly consider the differences in the learning experiences within contexts, and what differences the learner has to cope with while learning in each different context. It is our point of view that when looking at the different dimensions of seamless learning, the foundation from a learning theory perspective seems as yet insufficiently conceptualised. This point was confirmed in several expert interviews conducted with leading researchers and practitioners of seamless learning in 2017/2018 (publication in preparation).

Wong and Looi (2011) mapped the state of the art at that time by conducting a systematic literature review and identified 10 dimensions of seamless learning. Wong (2012) later refined this work. They structured and visualised the dimensions as the mobile seamless learning (MSL) dimensions. Dimensions 3 and 4 (MSL 3 and MSL 4), which are defined as learning across time and learning across location, are the two most universal dimensions and are visualised at the highest level in the model. Across time and location, seam learning should encompass:

- MSL 1—formal and informal learning,
- MSL 2—personalised and social learning,
- MSL 6—physical and digital worlds.

Moving across these multidimensional learning contexts, a learner may use multiple devices or a 'learning hub' (MSL 7) in order to mediate learning in these contexts. These devices allow for ubiquitous access to learning resources (MSL 5) and to encompass multiple pedagogical learning activity models (MSL 10). With the interplay of all previously mentioned dimensions, a learner will be able to perform and seamlessly switch between multiple learning tasks (MSL 8) (e.g., data collection, analysis, and communication), which may lead to knowledge synthesis (MSL 9) (Wong, 2012).

We, however, see indications for potential further development based on a learning theory conceptual backbone:

(1) Different MSL dimensions tackle very different aspects when it comes to the learning experience. First, there are context factors (e.g., learning in different time and place conditions, learning in different social structures, access to different learning resources and multiple devices). Second, there are different modes of learning (e.g., formal and informal learning, physical and digital learning, multiple pedagogical models). Third, there are different methodologies to learning (e.g., multiple learning tasks, knowledge synthesis). The different classification of the MSL dimensions results in different questions such as how the learner has to cope with different learning opportunities, a change of mode, or a change in beliefs and assumptions about learning, or to gain different learning outputs or outcomes.

(2) In the descriptions of mobile seamless dimensions, the surface structural elements (such as practical circumstances) are especially highlighted. But, what does learning across different contexts really mean for the learning processes and the development of competence? From a learning theory perspective, the challenge is to look for the differences in the individual requirements that a context leads to. While on the surface one can easily describe the differences in different time logic (e.g., synchronous or asynchronous), it is more difficult, yet necessary, to ask what the consequences of those differences are to the learning experience (e.g., difficulty of delayed response within asynchronous forms of learning and the higher necessity for timing one's own experience compared to synchronous forms of learning).

The question we want to address in this chapter is: What does the linking or bridging of contexts really mean from the learning perspective? Through this endeavour, we want to specify the final objectives of seamless learning. 'What is, and makes, the difference in the learning process and learning outcomes from one context, one modality, one approach compared to another?' Without deeper understanding of these differences, seamless learning approaches may fall short, leading to a focus on aligning contexts to one another in order to make them appear seamless (e.g., use of the same ICT tool in school and for homework or free time activities, or the formalisation of informal learning phases). This reduced understanding neglects to address the fundamental notion that learning is contextualised (Sharples, 2015). If a learner changes context, they need to be equipped with the appropriate competence in order to link the different knowledge structures, to switch between different skill sets or strategies, to change attitudes or beliefs or at least to be able to cope with the ambiguities of different learning context requirements.

In this sense, we aim for a broad seamless learning approach which includes (a) both ideas of bridging and aligning contexts, (b) a deeper understanding of the differences between contexts, modalities, and output/outcome and their consequences for the learners' experience, and (c) supporting and empowering students to manage switching between contexts themselves and integrating the different experiences in their competence. Therefore, the role of educational designers and faculty is not only to offer good designs, interventions, and support, but also to scaffold and prepare students in order for them to learn in this way. Wong (2013, p. 319) argued that in order to nurture genuine self-directed seamless learners, practitioners ought to develop and enact systematic and cyclic facilitated seamless learning processes to enculture the students. In this way, seamless learning becomes not only a pedagogical 'strategy' that can be designed and enacted by educational designers and faculty, but also a self-nurtured habit of mind of the learners (Wong, 2013, p. 320).

The word seamless implies that seams are lacking, something negative, something to be avoided. This interpretation should be treated with caution (cf. chapter on seamless writing in this book for a similar assessment in a different domain). The experience of seams can also be conceptualised as a trigger for learning (Bronkhorst & Akkerman, 2016). For instance, because ambiguity between fragments of knowledge provokes thinking and then the re-thinking of previous knowledge (Mezirow, 1997; Schön, 1983), this raises the question if seamlessness is the 'right' objective for educational design processes that aim to enhance learning.

In accordance with the vision of Lackner and Raunig (2016), who argued for seam-aware learning rather than seamless learning, we want to address the differences and the consequences of those differences primarily from a learning perspective (cf. Sects. 2 and 3). Based on that, we developed a set of learning strategies that supports learners in switching and integrating the different learning experiences. As a final step, we take a brief look at different pedagogical design principles in order to analyse their potential of fostering those learning strategies.

2 Problem Analysis I: Differences in Contexts, Modalities, and Output/Outcome

To analyse the differences between learning contexts, modalities, and output/outcome where and as learning take place, we build upon the seamless learning dimensions derived by Wong and Looi (2011). As described in the introduction, learning across different contexts can fragment learning experiences. In order to be able to make use of learning experiences from one context within another, they should be transferable between contexts. The notion of transfer includes very different sub-processes that a learner has to execute in order to work with learnings from one context within another. It includes processes such as becoming aware of the context-bound nature of experience, reflection on specific conditions within a certain context, the necessity of de-contextualisation from one learning setting, constructing a link between different contexts, adapting for the requirements of the different context and re-contextualisation within another learning context. All these sub-processes require cognitive strategies (e.g., qualitative case comparison), higher-order cognitive processes (e.g., meta-cognition), and motivational processes (e.g., resource strategies).

2.1 Underlying Differences of Different Context Aspects

Looking at different context variables, which vary in different contexts, raises the awareness of existing differences in the learning environments and in the given learning opportunities. Tabuenca et al. (2014) phrased it as the challenges to bridge learning activities between different contexts. With a look from situated learning theory, Cobb and Bowers (1999) stated:

> Situation and context, as they are characterised in situated learning theory, can be traced to the notion of position as physical location. In everyday discourse, we frequently elaborate this notion metaphorically when we characterize ourselves and others as being positioned with regard to circumstances in the world of social affairs (p. 5).

To better understand the problems in learning in different contexts, one has to carefully analyse the context variables and their deeper significance to the learning process.

The following dimensions place emphasis on different contextual factors:

- across time (MSL 3),
- across locations (MSL 4),
- personal and social (MSL 2),
- ubiquitous access to different learning resources (MSL 5), and
- multiple devices (MSL 7, and partly in MSL 5 and MSL 6).

When moving across different contexts, learners have to cope with differences in context variables. Therefore, they have to become more and more aware of the changes in those variables. Situational awareness (Endsley, 1995, p. 35) means to focus on the relevant and different aspects of a situation. The following aspects are seen as relevant from a theory of situation (Beck, 1996, p. 87). The aspects highlight not only those relevant within a given context, but also different specifications in given situations in order to compare them:

(a) Content complexity;
(b) Information uncertainty;
(c) Learning space and learning time differences;
(d) Social structure;
(e) Action regulation.

In the following subsection, we combine the MSL dimensions with the situational aspects to reinterpret the requirements.

2.1.1 Content Complexity

Complexity in regard to content rises when learners have access to very different learning resources and have to assess the quality of the learning resources (especially the validity) by themselves. With regard to content complexity, the differences in ‘learning resources’ and ‘multiple devices’ stress the necessary flexibility of the learner in working on different content dimensions such as differences in scope (narrow and broad) and depth (surface and deep). Also, technology as multiple devices plays an important role. For example, it makes it easier to transport artefacts (representing learning experiences) across different settings. However, at the same time, different technology multiplies content complexity.

2.1.2 Information Uncertainty

The context aspect of information uncertainty shows the differences in contexts regarding the quality of the given information. The quality of the given information within a context can be exhaustive or partial. At the same time, the information is either more definite or more probabilistic. The MSL dimensions of 'ubiquitous accessibility of learning resources' and 'multiple devices' require the learner to become aware of and to cope with different levels of information uncertainty, and to transform information in order to guide individual action.

2.1.3 Learning Space and Learning Time

'Independency from time and space' to learn concerns learning across contexts in the meaning of learning whenever and wherever a student is motivated. When learning processes become increasingly independent of time and spatial limitation, it enhances autonomy but places more responsibility on to the shoulders of the learner. The difference with regards to timing can be described as a difference in synchronicity between the learning and the teaching process. If both processes are designed in a synchronous manner, the learner is guided at a given pace and within a given time framework. With learning that can or should happen anytime, the learning process becomes more and more asynchronous from the teaching process. The learners themselves have to lead the pace and to define the time framework (Garrison & Kanuka, 2004, p. 97). Differences in learning spaces can be seen in the intentional design of learning spaces (e.g., acoustics, pressure to act); whereas, if learning takes place in real-world settings (e.g., the workplace), the conditions are designed to support primarily the work processes and not necessarily the individual development process (e.g., if a work process involves clients and learning has to be integrated in a performance task in front of a client). The MSL dimension of 'across locations' draws the attention towards flexibility within space, but also highlights different availabilities. Because of this, the learner has to make decisions regarding their own learning environment by himself.

2.1.4 Social Structure

The MSL dimension 'personal and social learning' stresses the differences in the social structure of a learning process. Personal and social learning not only differ in transparency (the individual learning process is more transparent to oneself than learning processes of others and their alignment between the two). The change from personal to social learning also requires that implicit aspects of learning have to be made explicit and communicated. Changing the social structure in the context leads to a whole other set of requirements with regard to making internal processes visible, finding the right expressions, and communicating or further collaborating.

2.1.5 Action Regulation

Different contexts provide different levels of autonomy to the learners. A learner-centred approach will give more room for the actions of the learner; whereas a teacher-centred approach will concentrate the governance upon the teacher. Autonomy in a given situation can be defined on a continuum from low to high. From the perspective of situational theory, it is important to look for different schemas the situation thrives for. Situations that can be coped with in a schematic way are less complex than situations in which only heuristic approaches can be employed. The MSL dimensions of 'ubiquitous access to different learning resources' and 'multiple devices' stress the underlying aspect of action regulation. Multiple devices vary in the required action regulation and choices have to be made by the learners themselves.

To summarise, different authors emphasise the flexibility of seamless learning with regard to situational aspects. For example, Chan et al. (2006) referred to seamless learning as situations where individuals can learn whenever they want to learn in a variety of scenarios, and where they can switch from one scenario to another easily and quickly whenever they want to do so, by means of personal mobile devices. This summarises the requirements of learning in different contextual factors. The five situational aspects (content complexity, information uncertainty, space, and time constraints, social structure, and action regulation) help us to better understand the meaningful differences that learners have to work with while changing contexts.

2.2 Underlying Differences of Different Learning Modalities

Different learning modalities highlight different forms of learning processes and the overall gestalt of the learning. Within the notion of learning modalities, we address the differences in the principle understanding of learning. It is therefore necessary to take a closer look at the dimensions which address modality, because it gives a very basic understanding on the concept of learning and the seams between the different understandings of learning.

Wong (2012) describes different mobile seamless learning dimensions which address the differences in the understanding of learning:

- Formal and informal learning (MSL 1),
- Physical and digital learning (MSL 6),
- Multiple pedagogical models (MSL 10).

2.2.1 Formal and Informal Learning

Within the first dimension (MSL 1), the seam between formal and informal learning emphasises the potential that can be unleashed through the informal learning process. Informal learning not only seems important to lifelong learning (Chen, Seow, So, Toh, & Looi, 2010; Wong, 2013), it also holds the answer to motivational issues commonly associated with formal learning settings. They all try 'to extend formal learning time, usually limited to the classroom, into informal learning time, to embrace opportunities for out-of-school learning driven by the personal interests of students' (Chan et al., 2006, p. 6).

On the surface, the difference between formal and informal learning is based on different learning spaces, where either the learning is happening, or who initiated the learning process (teacher or learner). Formal learning is learning within the classroom environment or within an explicitly educational context. Informal learning is regarded as learning in real-world circumstances and, therefore, mostly in non-educational contexts. Taking a closer look, the difference is distinguishable when one considers if learning happens intentionally or incidentally (for a discussion on seamless learning, cf. So et al., 2008). Stealth learning happens when learning takes place without recognition of that learning whilst it is happening and with no notion of learning goals or necessary learning environments and designs. This potential for informal learning opens up new options for individual development. Wong (2012) suggested that: 'a seamless learner should be able to explore, identify and seize boundless latent opportunities that his daily living spaces may offer to him (mediated by technology), rather than always being inhibited by externally-defined learning goals and resources' (p. E22).

A seam-aware understanding of learning prepared students with different sets of understanding and learning strategies: Formal learning is adapting to learning goals; whilst informal learning is supporting immersion in the action and its reflection. Students efficiently follow predefined learning goals and learning strategies within formal learning. In informal learning, orientation is to new fields without knowing where that action is heading, with further enquiries often required along the journey. To link formal and informal learning is to look for learning opportunities in the real world and to bring them into the classroom. Also, it is relating explicit goal-oriented predefined learning actions to development actions based on self-curiosity and interest, which are mainly implicit and not goal-oriented.

2.2.2 Physical and Digital Learning

We associate 'physical and digital learning' to the differences with regard to learning modality too. On a very practical side, digital learning opens up a toolbox of different forms of informational presentations and algorithms with which to work. With digital tools for data, information, and knowledge representation, instruction and construction of MSL 6 would be one element of the differences in regard to context. But in seamless learning methodology, we see another important level of understanding in the notion of ‘physical and digital learning’.

By encompassing physical and digital learning, different modalities of experience are tackled. Analogue learning can be experienced through different sensory perceptions and with direct impact on the feeling. Digital learning is learning mainly on the cognitive level and in a more abstract way, since the data and information are only documented experiences. Relating to Dale’s idea of an experience taxonomy (1969), the first-person’s experience in all-day or dramatised experiences, has a direct overall impact on the person, while verbal and visual symbols are abstract and link the meaning to the underlying experience, but it is more a general or second- or third-hand experience.

The difference between ‘physical and digital learning’ also focuses on the differences between the syntactic and semantic levels of information and knowledge. While we use many symbols to describe and categorise objects in the context, the symbols are not identical with the objects. With the help of the symbols on a syntactic level, we are able to signify the object. The digital sphere exists of those symbols and their combination (e.g., ontologies). The semantic level gives significance and meaning to the syntactic level. The interpretation and value-based appraisal of information lead to significant information and individual knowledge. Analogue learning integrates more the syntactic and the semantic level, whereas in digital learning, the necessary interpretation and validation have to be made explicit—it is a human ability, which cannot be replaced by artificial intelligence, well, not yet at least.

The profile of ‘physical and digital learning’ has to be more clearly understood, and the transitions from one modality to another become of significant importance. When we focus on student competence development, then it is important to enable them with strategies with which they can bridge the different modalities themselves. Bridging different levels of abstraction requires a student to identify the information content, regardless of its original form and has to express it in a different form (e.g., from a direct sensory perception, to data-based description, written text, or to a function or a graph). Digital learning, on the other hand, calls for a more explicit validation and signification by the individual, since the meaning one puts into information and knowledge is value based and mainly on the semantic level. Providing students with the ability for value-based thinking and action is therefore of greater significance (Erpenbeck & Sauter, 2013, p. 14).

2.2.3 Multiple Pedagogical Models

‘Multiple pedagogical models’ (as seen in MSL 10) address the variability of understanding of learning. Different pedagogical methodologies as in behaviouristic, cognitive, and constructivist learning theory traditions (Reinmann, 2015, pp. 136–144) differ in their understanding of learning. The behaviouristic learning theories place emphasis on the input–output relation. The cognitive learning theories emphasise the different cognitive sub-processes in learning. The constructivist learning theories put the focus on the self-regulated construction of knowledge and meaning in a social context. Building upon these different understandings, the ideas of how learning and teaching are conceptualised and understood somewhat differ. Learning goals, different disciplines, traditions and pedagogical knowledge and beliefs of teachers influence the pedagogical methodology employed in the design of a learning setting or a specific didactical intervention. The pedagogical methodologies differentiate themselves in regard to how learning is activated, the learning process is understood, and the possibilities of supporting learning through teaching and learning outcomes. There is no primacy to a single pedagogical methodology.

Looking on the surface, multiple pedagogical models provide students with increased freedom and choice to find their individual fit. Looking with a deeper understanding of the pedagogical methodology differences, each approach works with a different set of epistemological beliefs (e.g., whether the nature of the knowledge is predefined and structured by an external authority or is negotiated in a social communication process) and pedagogical beliefs (e.g., whether the learning is more a matter of transmission of knowledge or an individual construction process). Those beliefs tend to be stable, but have potent influence in their action. Flexibility between different methodologies has to be systematically trained and developed. To enhance students' flexibility, both individual beliefs as well as consequences of a certain methodology have to be reflected.

2.3 Underlying Differences of Different Output/Outcomes

The last two dimensions point to pedagogical output and outcomes. They play a crucial role, since it is the output/outcome which defines the agenda of a learning process. The dimensions of 'multiple learning tasks' (MSL 8) and 'knowledge synthesis' (MSL 9) are the two dimensions that concern output and outcome.

2.3.1 Multiple Learning Tasks

Multiple learning tasks indicate the relevance of different modes of output of a learning process. The variety of differences is significant. This dimension in the model can be interpreted as a demand for more variety in the requested performances leading to respective outcomes. It can also be understood as a driver for competence flexibility. It is not a given or a trained set of challenges that is workable after the learning, but a flexible disposition which can lead to different competent actions.

Upon first sight, multiple learning tasks seem to call for more variety with a broader spectrum, with students better prepared for different requirements of the real world. So, seamless learning then leads towards better preparedness for the broad scope of challenges. After a more involved examination, the dimension of multiple learning tasks is seen to stress the importance of changing requirements and how to deal with differences in tasks. Through this understanding, and extending on the work of Wong (2012), the following processes become of more importance: analysing the different requirements, reflecting on one's own competence base, selecting single elements from the knowledge structure, the skill set, and the attitude, integrating the different elements, developing an action plan and its implementation, and reflection upon the outcome and the process.

2.3.2 Knowledge Synthesis

The 'knowledge synthesis' dimension addresses the ideal of the outcome of seamless learning. It forms the antidote to the problems of seams in learning. The understanding can be shown as learning happens in different contexts and modalities, which leads to the fragmented knowledge of students. Through deliberate linking and bridging activities on the seams, these seams can be removed, mitigated, or worked upon with awareness of their existence. This again leads towards an integrated knowledge base or knowledge synthesis. Knowledge synthesis, in this understanding, is the outcome of seamless or seam-aware learning. Knowledge synthesis is the basis of competence and competence development.

On the surface, knowledge synthesis could be described as a coherent, consistent, and comprehensive knowledge base. This is not easy to develop and even more difficult, when different sources, formal descriptions, beliefs, context factors, etc., are used in the learning processes. Looking deeper, one has to address the processes of integration, balancing, prioritising, value-based decision-making, critical thinking, and reflecting for the development of a well-integrated knowledge base. The concept of seamless learning emphasises that many different sources, ways, and outputs have to be linked together in order to create one overarching framework.

The dimensions in regard to the output and outcome address the learning process from its endpoint. They are important to consider, however, since they help to describe the desirable target.

In summary, this first problem analysis tackled the different problems underlying the mobile seamless learning dimensions from a learning perspective. The analysis was conducted in order to make the differences more visible and is the first step to supporting the understanding of the relevant seams in seamless or seam-aware learning. Also, it contributes an element to the necessary support as Tabuenca, Kalz, and Specht (2014) expressed: 'There is little support for lifelong learners that typically try to learn in different contexts, are busy with multiple parallel learning tracks, and must align or relate their learning activities to everyday leisure and working activities' (pp. 1–2). Table 1 summarises the dimensions, their categorisation in regard to learning, and the problem behind the seams.

Table 1 Summary of the problems behind the seams

MSL dimension (Wong, 2012)	Category of learning	Seams—surface level	Problems behind the seams
MSL 1: Informal–formal	Modality	Different learning spaces	Polarity of intentional and incidental learning
			Polarity of explicit learning and stealth learning
MSL 2: Personall–social	Context	Different social structures	Polarity of subjective and intersubjective knowledge
			Polarity of implicit and explicit communication of learning
MSL 3: Across location	Context	Designing learning spaces which allow for learning anywhere	Polarity of given context/specially designed learning environment and using any context as learning environment
MSL 4: Across time	Context	Designing learning spaces which allow for learning anytime	Polarity of given pace/rhythm and self-regulation
			Polarity of adaption and creation
MSL 5: Ubiquitous access to learning resources	Context	Availability/accessibility	Polarity of preselected and curated learning materials through learning designers, necessary validation, and selections process of an individual learner
MSL 6: Physi-call–digital	Modality	Different tools and systems	Polarity of different forms of representations and its transformation
			Polarity of syntactic and semantic learning levels
MSL 7: Multiple devices	Context	Availability/accessibility	Polarity of preselected and curated tools through learning designers, necessary validation, and selections process of an individual learner
MSL 8: Multiple learning tasks	Output	Flexibility	Polarity of different but still known assignments and training to deal with uncertainty and new challenges
MSL 9: Knowledge synthesis	Output	Coherence, consistence, and comprehensiveness	Polarity of product and process perspective, necessary processes of integrating, validating, and reflecting
MSL 10: Multiple pedagogical models	Modality	Choosing the most efficient and effective	Polarity of adapting to a given methodology and benefiting from it; selecting, validating, and creating an individual approach

3 Problem Analysis II: Differences in the Understanding of Learning Processes and Learning Aims

3.1 Learning Process

Learning occurs in the interaction of a person and their environment. This classic understanding draws back to Piaget and his primary learning understanding (Piaget, 1952). This understanding involves perception, transmission, experience, imitation, activities, and learners interact with different objects in different contexts, which lead to changes in their internal dispositions. Knud Illeris differentiated four types of learning: (1) cumulative or mechanical learning, which is characterised by isolated knowledge formation; (2) assimilative learning or learning by addition, which means new items are linked to existing categories or patterns; (3) accommodative or transcendent learning, which breaks down existing patterns and develops new patterns; and (4) transformative learning, which occurs when the basic assumptions and understandings are put in question and changes occur on a principle level (Illeris, 2009, pp. 13–14).

The understanding of learning within the seamless learning literature, although not always clearly defined (Nicholas & Ng, 2015), tends to connect more to the accommodative and transformative understanding of learning. The problem analysis in Sect. 3 shows the polarities of different understandings and different ideal characteristics towards the different learning aims in regard to:

(a) Knowledge structures;
(b) Skills;
(c) Attitudes/beliefs.

3.2 Differences in Regard to Learning Aims

3.2.1 Knowledge Structures

With regard to knowledge, seamless learning brings into focus the very different understanding of knowledge and its characteristics. The principles of seamless or seam-aware learning highlight the need for a more complex conception of knowledge. With careful consideration of the seams and the problems that may lay behind them, it is evident that knowledge structures are no longer seen as discipline-specific, objective, well-defined, fixated and traditionally instructed units.

The deficiencies visible in learning designs, which only address singular knowledge elements and downplay multiple relations, causes phenomenon like inert knowledge, routine knowledge, fragmentation , and increased non-valid knowledge

(Perkins, 1999, pp. 7–8). Seam-aware learning designs strive towards knowledge structures, which can be described by attributes such as:

- Action-oriented,
- Intersubjective,
- Complex,
- Fluid,
- Multidimensional,
- Multiple representation forms, and
- Developed in a self-structured way.

In the words of Stephen M. Kosslyn, this kind of knowledge structure would be seen as practical knowledge or 'knowledge one can use to adapt to a changing world, which allows one to achieve one's goals' (Kosslyn, 2017, p. 18). The aim for the development of knowledge structures is then not only in the idea of cumulative or assimilative learning, but as part of an ongoing, flexible, and permanently changing knowledge base.

3.2.2 Skills

Skills listed in the CEDEFOP glossary (2008) include the ability to perform tasks and to solve problems, which therefore connects them more to the procedural aspect of knowledge. Looking at the aforementioned problems that may lay behind the typical seams (cf. Sect. 2), it could be said that a change in understanding occurs also in regard to skills. Limitations in a functionally bounded and context-specific skills training lead to skills development which follows a mechanical algorithm or script, and which are mostly instructed in an explicit manner and reproduced only within transfer contexts of identical requirement. This, however, does not match the educational aim of adaptation of a learner's skill set to a predefined skill. Through the notion of seamless or seam-aware learning, the challenges to strive higher and skills development are oriented towards being more accommodative, agile, and transformative (Illeris, 2009). Heuristic problem-solving skills, which are embedded within a situation and can be recreated and not only reproduced, in order to gain relevance and significance. Also, the ability to utilise and implement those skills in different social structures and dynamics is much needed. Overall, it can be summarised that the aim for future skills development is providing learners with the abilities to govern his or her own actions and reflections.

We are thus the learning species, and our survival depends on our ability to adapt not only in the reactive sense of fitting into the physical and social worlds, but in the proactive sense of creating and shaping those worlds (Kolb, 2015, p. 1)

3.2.3 Attitudes/Beliefs

Affective and motivational aspects are considered in the element of attitudes or beliefs. It is probably the most disordered aspect of an individual's disposition, but the influence in the interpretations, decisions, and actions is considerable. Thus, there is an increased need for developing attitudes and beliefs. In the literature on beliefs, one can differentiate between epistemological beliefs from the pedagogical beliefs and domain-specific beliefs (Blömeke, Felbrich, Müller, Kaiser, & Lehmann, 2008, p. 722; Pajares, 1992, p. 316). Applying problem analysis on a deeper level shows that polarities also on beliefs are addressed within the seamless learning context.

In regard to epistemological beliefs, there is a shift towards the more complex pole of the continuum. For example, the source of knowledge is no longer seen as the naïve concept of an omnipresent authority, but leans more towards the idea of a socially constructed and negotiated source. Beliefs towards the certainty of knowledge are no longer characterised by the idea of an absolute status, but are attributed more and more as dynamic and ever-evolving. Beliefs with regard to the structure of knowledge are developing away from the naïve approach that knowledge structures can be analytically decomposed in single units and are only linked in a hierarchical manner towards the belief that knowledge structures are very complex and closely interconnected on multiple levels. Considering pedagogical beliefs, also different shifts in the beliefs can be addressed in the context of seamless learning. No longer relevant are the naïve assumptions of learning (e.g., that learning is genetically given or that learning either happens quickly or not), but more complex beliefs (e.g., that learning can be trained) are seen as more important. Beliefs that learning is a strategically important ability, which can be trained and developed, and that learning is a gradual process (Schommer, 1990), are more likely to support the ideal understandings of seamless learning. One can also link the shifts in the beliefs back to the understanding of learning, according to Illeris (2009), that the higher developed beliefs are in line with the understanding of accommodative and transformative learning.

We conducted Problem Analysis II in order to identify where the concept of seamless or seam-aware learning addresses different understandings from a learning perspective. The two dimensions highlighted follow the distinction of learning process and learning aims. With the described orientation on accommodative and transformative learning in the learning process, seamless learning addresses higher-order learning processes. This transparency helps also to consider learning designs, which have the potential to actively support such qualities in learning. Also, more complex aims become part of the focus. With the differentiation of knowledge, skills, and attitudes/beliefs, we propose that the aims of seamless learning can be made more transparent and clearer. Seamless learning can support the operationalisation of learning goals and, as a consequence, provide clarity of understanding for the necessary learning design strategies.

Before we address suitable design principles, let us take a closer look at the learning strategies that the single learner has to be equipped with in order to be able to learn across contexts, and to be able to bridge any differences in knowledge structures, skills, and beliefs that may be required within the different contexts.

4 Learning Strategies—A Necessary Component in the Seamless Learning Approach

As mentioned in the introduction, we see the need for a comprehensive and broader understanding of seamless learning. The alignment and integration of context are one measurement on the surface that helps to work around seams and support seamless learning through the reduction of seams. A more fundamental understanding has been developed with the help of the two problem analyses (see Sects. 2 and 3), showing that especially differences in the understanding of learning process and learning aims (differentiated in knowledge structures, skills, and attitudes/beliefs) in different contexts are potent characteristics of seamless or seam-aware learning approaches. In order to enable learners to switch deliberately between contexts and to offer them the support that they need, one of the main pedagogical aims of seamless learning is to encourage students to integrate their different learning experiences within their own competence. To link the discussion to the ongoing educational theoretical discussion, we chose the concept of self-regulated learning, since it is not only the most important research area in educational psychology, but also conceptualises the empowerment of the single learner in their own learning process regulation (Sha, 2015).

Self-regulated learning is an 'extraordinary umbrella under which a considerable number of variables that influence learning (e.g., self-efficacy, volition, cognitive strategies) are studied within a comprehensive and holistic approach' (Panadero, 2017, p. 1). It seems to be a solid foundation for the future conceptualisation of seamless learning. Zimmerman, with his model of cyclical-phased self-regulated learning, specified three phases such as (1) forethought, (2) performance/volitional control, and (3) self-reflection. Within these phases, Zimmerman identified sub-processes within the self-regulated learning model (Zimmerman, 2000). Based on that, we then combined these sub-processes with the necessary strategies for seamless or seam-aware learning (see Table 2).

By adding the specific strategies for seamless or seam-aware learning to the basic self-regulated learning model, one can demonstrate that the positioning and interaction of the individual within the context, and consequently strategies, which supports sensitivity towards the contextual influence on the learning experience have to be added. This supports the notion that seamless or seam-aware learning leads to an understanding of learning, in which the learner acts as self-regulated, being aware of how context impacts their experiences.

Table 2 Integration of self-regulated learning with seamless learning

Phases	Sub-processes within self-regulated learning model	Additional sub-processes within seamless learning model
Forethought	Task analysis (goal setting, strategic planning)	Subject–context awareness (sensibility of relevant factors with specific context for individual learning experiences)
	Self-motivational beliefs (self-efficacy, outcome expectations, intrinsic interest, value, goal orientation)	
Performance/volitional control	Self-control (self-instruction, imagery, attention focussing, task strategies)	Self-accommodation and transformation (breaking down existing patterns to become aware of one's own misconceptions and restructuring own knowledge, skills and beliefs)
	Self-observation (self-recording, self-experimentation)	Self-validation (value-based judgement, validity analysis, and meaning-making)
		Self-integration (integrating multiple aspects, working with diversity, linking different perspectives)
Self-reflection	Self-judgement (self-evaluation, causal attribution)	Self-reflection (of own knowledge, skills, and beliefs)
	Self-reaction (self-satisfaction/affect, adaptive–defensive)	Self-agility (de-contextualising and re-contextualising)

5 On the Way to Seam-Aware Learning Design Principles

The analysis of seamless learning from a learning perspective fosters a better understanding of the learning processes, both within and across different contexts. Through the examination of defined problems, a more specific concept of seam-aware learning can be developed. Linking to the discussion on self-regulated learning helps to specify the expected educational learning goals that seam-aware learning approaches are aimed towards. This extensive analysis is important in order to better inform educational designers about the broader understanding of the seamless learning concept, but also to select viable design principles for seamless learning projects going forwards.

In the context of seamless learning, Looi and Seow (2015) and Zhang et al. (2010) developed and improved the following design principles:

- Design for emergent learning and for personally and socially meaningful goals,
- Making thinking visible,
- Planning adequate time to perform learning activities,
- Design for technology ready-at-hand (in and out of class),
- Design for seamlessness (bridging across contexts),
- Design alternative assessments (to test new competencies),
- Design not for direct conversion from paper-based curriculum.

The underlying notion of those guiding principles is to overcome seams by linking the contexts together, in order to avoid seams. Within our analysis in Sects. 2 and 3 of this chapter, we looked for a deeper understanding of the seams. There is a need to support educational designers with the aforementioned relevant principles. Further development in design principles for seam-aware learning has to take into account the specifics of the problems.

In a first approach, we see high-impact pedagogies (Evans, Muijs, & Tomlinson, 2015) as a valid source of design principles with regards to seamless learning. These high-impact pedagogies address the specific understanding of the learning context, learning process, learning goals, and the learning output and outcome that seamless learning is primarily targeting. High-impact pedagogies and their theoretical foundations form a conceptual framework for pedagogical design principles which foster active and self-regulated learning, including problem-based learning, experience-based learning, enquiry-based learning, situated learning, peer learning, game-based learning, design-based learning, project-based learning, and self-regulated learning. What all of these approaches have in common is that they are based on an active, constructive, and contextualized understanding of learning. This is what qualifies them as potential sources for design principles for seamless learning from the beginning.

In a second step, we link the specifics of those learning design approaches to the problems of the seams. Based on that, they provide more specific guidelines in the design process and direct the seam-aware learning designs to working explicitly with the problems behind the seams (Table 3).

With the selected aspects from the high-impact pedagogies, the first design hypotheses for seam-aware learning were developed. In an ongoing research programme, those design hypotheses will be tested within an empirical field. Through the evaluation of the designs following those design hypotheses, seam-aware design principles will be further developed. This chain between seams and the problems that may lay behind them, the necessary competences and design hypotheses potentially close the current gaps in the context of seamless learning. Following this chain will allow us to become more specific in our designs, as well as to scaffold the educational designers' knowledge with evidence-based guidance to incorporate within their design processes.

Table 3 Design hypotheses deriving from high-impact pedagogies

MSL dimension (Wong, 2012)	Sources for relevant design principles and design hypotheses
MSL 1: Informall–formal	Experience-based learning (Kolb, 2015), since it allows to transform experience with implicit learning through reflection into an explicit learning experience
MSL 2: Personall–social	Peer learning (Toping & Ehly, 2001), since it addresses the potential of knowledge production through social communication and interaction
MSL 3: Across location	Situated learning (Wenger, 2009), since it allows for intentionally addressing the changes in context
MSL 4: Across time	Self-regulated learning (Zimmerman, 2000), since it actively defines learning competences and methods in order to scaffold external support and enhance self-regulation
MSL 5: Ubiquitous access to learning resources	Enquiry-based learning (Engeström, 1999), since it addresses the information need and the validation of information and its reorganisation as explicit goals
MSL 6: Physicall–digital	Design-based learning (Doppelt, 2006), since it is based on the transformation of concrete and abstract knowledge and it works on transforming inner knowledge in externalised prototypes, and therefore works with different forms and principles of information representation
MSL 7: Multiple devices	Enquiry-based learning (Engeström, 1999), since it addresses the tools needed and the usability and viability of tools for thinking as explicit goals
MSL 8: Multiple learning tasks	Enquiry-based learning (Engeström, 1999), since it places emphasis on open questions as the starting point of enquiry
	Problem-based learning (Barrows, 1986), since it defines problem types and sets problems as incentives for learning and development
MSL 9: Knowledge synthesis	Design-based learning (Doppelt, 2006), since it is based on the transformation of concrete and abstract knowledge and works on transforming inner knowledge through externalised prototypes
	Enquiry-based learning (Engeström, 1999), since it emphasises the cognitive aspects of integration, validation, and reflection. For the affective and emotional level of integration, validation, and reflection, there is a lack in educational design approach
MSL 10: Multiple pedagogical models	Self-regulated learning (Zimmerman, 2000), since it actively governs and enhances the individual learning strategically
	All high-impact pedagogies are based on different constructive learning theories (Illeris, 2009), so the scope of variation on multiple pedagogical methodologies is predefined to them. This neglects methodologies, which have their foundation in behaviouristic or cognitive learning theory

6 Conclusion

Although the seamless learning concept has fostered many different project initiatives and conceptual considerations, we see potential shortcomings in their arguments. The majority of projects combine the concept of seamless learning with aligning different contexts towards a single set of requirements. We explicitly see the connotation of seam-aware learning with greater potential and relevance in order to address the real challenges of learners and their learning experience. This is not with the aim to overcome or reduce seams, but to work with seams as potential learning opportunities. It is our recommendation to consider the specific requirements of learning experience and learning context diversity as the future-safe approach in education. Looking at the concept of seamless learning from the learning perspective helps to uncover the relevant problems that occur within the learning process. From our perspective, the learning theoretical foundation of seamless learning as a concept should be developed further. Future research should address the conceptual assumptions from the learning perspective. Also, the beliefs of educational designers with regard to the learning processes and learning aims of seamless learning projects should be taken much more into account for the specification of a seam-aware learning concept.

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Chapter 3
External Representations and the Design of Seamless Learning Systems

Toward a Conceptual Framework to Analyze Empirical Evidence Regarding Learning Benefits

Nuno Otero and Ian Oakley

1 Introduction

Personal digital technologies such as laptops and mobile phones are being steadily introduced into traditional learning contexts such as schools. This advance is supported by a large body of academic literature highlighting the educational benefits that appropriate use of technology can provide—Sung, Chang, and Liu (2016) recent meta-analysis of 110 papers from the past 20 years, for example, shows a mean positive impact with a moderate (0.53) effect size over highly diverse conditions. The academic data is reinforced by commercial interest: a plethora of mobile device applications promise learning "anywhere, anytime" across the full spectrum of academic disciplines and targeting all student levels (Laru, Näykki, & Järvelä, 2015; Sharples, Arnedillo-Sánchez, Milrad, & Vavoula, 2009). Together, these streams of activity make mobile educational technology a vibrant area for both research and development that leverages and applies knowledge and outcomes from contributing fields as various as mobile technology, technology-enhanced learning, mobile HCI, and pedagogy.

However, despite the general consensus that beneficial effects can be achieved by integrating mobile technology into educational activities, there is remarkably little agreement on the specific techniques, methods, or mechanisms that can be used. We argue that current research and development efforts are, in practice, little more than hit and miss. To address this problem, a number of review articles have emerged that try to elucidate the opportunities and challenges researchers and practitioners

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face (see for example, Frohberg, Göth, & Schwabe, 2009; Lucke & Rensing, 2014; Wu et al., 2012). While these efforts are valuable, we note they emphasize coverage and practical characterization (e.g., of device form factors, activity types) over detailed or theoretically grounded critique. As such while they describe current state of the research field well in practical terms, there is still a need to guide the field toward theoretically driven research within the domains of pedagogy and/or educational psychology and related design approaches and strategies. Similarly, Wong and Looi (2011) provide an informative framework structured around consensus definitions of core properties of mobile seamless learning. While these frameworks are useful, we argue that research is currently needed to characterize the pedagogical benefits that seamless learning approaches can provide. Furthermore, we assert this can only be achieved through research that has a clear grounding on appropriate theoretical/conceptual frameworks and that reports empirical evidence.

This paper contributes to resolving this problem with a theoretically grounded discussion of the issues involved in designing seamless learning technologies from a key underlying, and evidence driven, research area: external or distributed cognition and, more specifically, the body of literature dealing with the creation, properties and use of *external representations* (Scaife & Rogers, 1996). This discussion can be contextualized in terms of Vavoula's and Sharples (2009) framework for evaluation of learning systems that postulates three core classes of analysis. The *micro-level* is concerned with learners' concrete activities when engaged with learning technology in terms of usability and/or utility while the *meso-level* considers the learning experience as a whole in order to identify breakthroughs and breakdowns. Finally, the *macro-level* examines the overall impact of learning systems on established educational organizations and practices. The goal of the current paper is to contribute an analysis of seamless learning technology at the micro-level—to explore the usability and utility of existing seamless learning systems from the perspective of embodied cognition and in light of the existing body of empirical literature on external representations. This kind of theoretical analysis is important as it can provide explanations for existing results and guide future system design, development and, most critically, evaluation efforts. Only through adopting appropriate theoretical lenses will researchers in seamless learning be able to convincingly demonstrate the pedagogical value of the approach.

The remaining of the chapter is structured as follows. Section 2 provides a brief summary of seamless learning and argues for the relevance of distributed cognition and external representations as a foundational research area that can guide the future design, development and evaluation activities. Section 3 expands on distributed cognition and external representations in order to highlight their importance when analyzing technology-enhanced learning systems. In Sect. 4, we identify the key challenges that come to light when examining seamless learning from the perspective of the literature on external representations; these principally relate to the potential disruptions that emerge from the technological, social, and spatial transitions between contexts that are an intrinsic part of seamless learning systems. In Sect. 5, we propose ways to support these transitions based on existing literature on external representations. Finally, Sect. 6 describes key methodological issues that researchers will face when engaged with collecting and analyzing data to support theoretically/conceptually driven research approaches in applied areas such as learning technologies. The chapter closes with a summary of our contributions emphasizing the importance of strengthening the field of seamless learning with theoretical and conceptual frameworks that address the core pedagogical and cognitive issues that underlie it.

2 Seamless Learning

Wong (2015) provides a critical analysis of the history of mobile assisted seamless learning. He dates the emergence of the concept to the early 1990s and, specifically, to discussions highlighting gaps between teaching and learning activities that occur inside and outside of classrooms. The seminal reflections on the tensions and links between activities in these two contexts focused on understanding how to promote continuity between learning in schools and learning occurring outside—not only in homes but also during fieldwork or other assigned activities. Wong notes ideas from these discussions were adopted at the beginning of the twenty-first century by researchers in the field of mobile and ubiquitous learning.

Over the following decade, both technologies and ideas in this space further matured. In 2006, Chan et al. (2006) coined the term "seamless learning" to signify learning activities characterized by a continuity of experiences across different learning contexts and enabled by new interactive features provided by mobile and ubiquitous technologies. According to Chan et al., seamless learning scenarios can encompass individual learning experiences through paired activities (with another student) to a small group or a large online community use, with possible involvement of teachers, relatives, experts and members of other supporting communities. They may also take place face-to-face or remotely using various modes of interaction and be situated in places as diverse as classrooms, homes or other informal settings and outdoor environments, parks, and museums. In Chan et al. (2006), learning contexts consist of configurations of these kinds of activities, material resources and relationships in both colocated physical or virtual spaces that provide novel opportunities to support learning.

One implication of this broad scope of this definition of learning contexts is the inherent complexity it entails in terms of supporting transitions between different environments, activities or scenarios (Looi, Seow, Zhang, So, Chen, & Wong, 2009). Seamless learning experiences can facilitate connections between concrete hands-on experiences, symbolic representations and abstract concepts across different learning situations both outside and inside the classroom (Sharples, Milrad, Arnedillo-Sanchez, & Vavoula, 2009; Spikol & Milrad, 2008). Rogers and Price (2009) add that features of digital mobile collaborative tools emphasize the situatedness of learning experiences (for example, by explicitly grounding learning activities through the use of sensors and in situ informational resources). In turn, this might emphasize the role that embodied interactions play in learning processes, enabling continuity between learning experiences and facilitating learners' reflections toward the understanding of the connections between what they are observing, collecting and thinking. Making salient the connections between learning situations and helping learners understand them is central to seamless learning. As such, it seems necessary to conceptually and theoretically elaborate how to design these connections. As a step to achieve this, Wong (2015) identifies some theoretical and conceptual frameworks that have influenced work in the area of mobile assisted seamless learning. Of particular interest to this present paper is the distributed cognition approach. Looi et al. (2009) also propose that seamless learning can be framed according to the guiding principles of distributed cognition theory.

In summary, researchers in seamless mobile learning are exploring the potential of ubiquitous and mobile digital technologies to enable the creation of learning activities that promote continuity between distinct learning contexts. Furthermore, the widespread use of mobile digital technologies also allows researchers to design learning situations where learners have individual and permanent access to powerful computational devices. However, in order to be able to design effective learning situations that involve transitions across contexts, researchers need to take into account theoretical/conceptual frameworks that elaborate on the specifics of the distributed nature of the learning activity they employ. The framework of distributed cognition, and specifically work on external representations is particularly relevant to this endeavor.

3 External Representations

Scholars in the area of distributed (Hutchins, 1995; Hollan, Hutchins and Kirsh, 2002; Perry, 2003) cognition have long asserted that human cognitive processes cannot be fully accounted for by explanations that consider only internal mental states and information. They claim that in many complexes, meaningful and everyday tasks, mundane acts of cognition are achieved through the activities that are fundamentally constituted from a combination of internal processes and external artifacts, situations and behaviors. Things, environments, people or other structures out in the world, they claim, form an intrinsic part of human cognition via a wide range of supporting mechanisms such as facilitating inference, enabling shareability and allowing explicit encoding of information (Kirsh, 2010).

Distributed cognition is an established approach to understanding learning activities—see Salomon (1993a) for an overview of distributed cognition perspectives in this area. More specifically, Salomon (1993b) and Dillenbourg and Betrancourt (2006) discuss the nature of the distribution in terms of cognition and learning processes, highlighting the need to understand interconnections between individual cognitive processes (what the solo learner acquires/learns), group processes (what the social interactions foster) and the contributions that specific external artifacts bring to those processes. A focus on the dynamics of this interplay leads to research that investigates the design of "knowledge in the world" and how this material helps or hinders cognitive activity (Scaife & Rogers, 1996).

Much of this knowledge in the world is expressed as *representations*: generated or designed structure that embodies critical information about and/or operations on some phenomena of interest. Representations *stand-in* for the original phenomena during cognitive work, by expressing, and in many cases, providing ready access to qualities that meaningfully characterize it. Palmer (1977) identifies five entities that play a role in defining any representation. These are: (1) the represented world, (2) the representing world, (3) the specific aspects of the represented world that appear in the representing world, (4) the specific aspects of the representing world are being used for representational purposes and (5) the mapping between the two worlds. The use of representations is a hallmark of cognition and a fundamental concept underlying theories of the mind (Paivio, 1990)

From the perspective of distributed cognition, external representations (ERs) are of substantial interest (see, for example, Kirsh, 2010; Scaife & Rogers, 1996; Zhang, 1997; Zhang & Norman, 1994; Zhang & Patel, 2006). Zhang (1997) defines ERs as "knowledge and structure in the environment" that includes arrangements of objects (e.g., pieces in an abacus or on a chessboard), written or drawn contents (e.g., a graph) as well as the rules, constraints or relationships that define and explain this content (e.g., the spatial relationships between contents on a graph or physical limits on movements of abacus beads). It is informative to map these more practical definitions onto Palmer's five entities (Palmer, 1977). For the example of an abacus, the represented world is the mathematical world of numbers, while the representing world is the beads and rods of the physical device. The specific aspects of the mathematical world embodied in the abacus is (at least) quantity and the aspects of the representing world being used in the system is the spatial arrangement of the beads on the rods. Finally, the mapping between the two relates to how the locations of the beads are used to signify quantities. External representations, in the form of symbols, scales, objects and external rules and constraints are a ubiquitous part of daily life.

External representations have also been widely studied in learning settings. Indeed, in many inherently abstract disciplines, external representations are a core part of all activity. For example, in mathematics, representational notation systems are used to express and manipulate all core concepts. Studying the discipline is arguably inseparable from studying its representations. Research has discussed the role that ERs such as diagrams (for example, Arcavi, 2003; Blackwell, Whitley, Good, & Petre, 2001; Cheng, 1998; Cox & Brna, 1994; Hegarty & Steinhoff, 1997; Larkin & Simon, 1987), interactive simulations (for example, Bodemer, Ploetzner, Feuerlein, & Spada, 2004; Boucheix, Lowe, Putri, & Groff, 2013; Byrne, Catrambone, & Stasko, 1999; Hegarty, 2004; Lowe, 2003) and virtual learning environments (for example, Ainsworth, Bibby, & Wood, 1998; de Jong et al., 1998; Otero, Rogers, & Du Boulay, 2001; Rogers & Scaife, 1998) can play in learning. While this literature has showcased the potential of the ER approach through compelling case studies, providing generalizable evidence of beneficial properties and guidelines to reliably produce them remains challenging. This is in part due to the fact that many learning environments leverage multiple ERs, making it hard to tease apart the benefits of each from, for example, the costs associated with moving between them (Ainsworth, 1999a; Ainsworth & VanLabeke, 2004).

In fact, issues of transitioning and translating between multiple external representations are of critical importance for the area of seamless learning. With its defining focus on diverse contexts spanning locations, devices and social groupings, representational shifts are inevitable—a representation that is appropriate for an individual fieldwork exercise, such as a citizen science style data capture experience (Sollervall, Otero, Milrad, Johansson, & Vogel, 2012) will likely differ substantially from a representation appropriate to discuss and collate the outcomes of several such exercises by a small distributed team (Sollervall et al., 2012) Recognizing the fundamental challenge inherent in representational shifts, researchers have sought to explore how it can be managed. For example, Rogers and Scaife (1998) propose *dynalinking*, referring to design elements that seek to make links between different interactive external representations explicit. They argue that supporting representational linking will promote more abstract levels of understanding. Additionally, they highlight the importance of a range of issues in ER design including explicitness and visibility, cognitive tracing, ease of production, combinability and modifiability.

The use of multiple representations has the potential to convey many benefits. Ainsworth (1999a, b) elaborates on these by presenting a taxonomy of the ways in which the use of multiple representations can support learning objectives. There are three key mechanisms: by acting in a complementary fashion; by constraining interpretation; and by supporting construction of deeper understanding. Complementary ERs can either be informationally equivalent, but differ in their presentation (for example to appeal to diverse individual preferences), or convey information that is, to a greater or lesser extent, unique. Presenting complementary ERs can facilitate access by a larger number of learners, or highlight different aspects of some topic of interest. Constraining interpretation refers to the fact that existing knowledge about representations can be applied to new representations, easing comprehension. Finally, multiple ERs can support deeper understanding by promoting processes such as abstraction, extension, or generalization of knowledge and by highlighting the links between different representations.

Finally, Vavoula and Sharples (2009) highlight the need to understand the impact of transitions between learning contexts and identify shifting between representations as an intrinsic feature of seamless learning environments. As learners move from one context to another, the representations deployed to support their activity vary to best fit the constraints and opportunities of the current context. Despite these observations, designing coherent, supportive and valuable sets of ERs across contexts remains a challenging task. This remainder of this article elaborates on the problems inherent in this task in the specific scenario of seamless learning.

4 Challenges Applying External Representations to Seamless Learning Systems

In the previous section, we presented a case for analyzing the design of the transitions inherent in seamless learning scenarios through the lenses of ERs frameworks. In this section, we apply ER frameworks to the specific challenges of designing seamless learning scenarios. We focus on three types of transition: between devices, between social settings and between physical spaces. These map loosely onto the symbolic, social and physical (or material) "kinds" of distributed cognition proposed by Kim and Reeves' (2007). In this work, symbolical distribution of cognition relates to the nature of the representations being used (signs, symbols, language, etc.), a concept closely linked to ERs. Social distribution of cognition focuses on social dynamics, how the information propagates across individuals and how norms and rules affect this propagation process. The way the information propagates across a group impacts the way it is able to "think" and make decisions. Finally, physical distribution of cognition highlights how visible and tangible objects encapsulate information and how particular arrangements of these objects in space affect the potential for thinking and acting by human learners.

The challenges we identify are connected to the impact of dealing with distinct settings and inevitable transitions between settings. While the following subsections deal with each challenge separately, we note there are inevitable interactions and overlaps between the issues in each challenge.

4.1 Physical Form Factor and Interactional Qualities

The form factor of the devices used in a seamless learning context impacts the ERs that can be effectively deployed. This is particularly apparent when considering fundamental device properties such as *screen size* that will vary considerably between different learning contexts: a large screen device (such as a PC) used in a classroom can present more information than a small-screen device (such as a mobile phone) used in a fieldwork or home setting. Indeed, researchers in information visualization have long acknowledged that designs for large screens cannot be simply shrunk down to fit small screens and maintain their usefulness (Chittaro, 2006). Arguably differences in the *interactional qualities* of different devices also impact the viability of ERs: the direct multi-touch systems common on mobile devices natively support a more diverse set of direct manipulation operations on displayed content than the more indirect input of mouse pointing and keyboard on a PC. Interactive ERs should be designed to leverage the properties of the devices they are presented on.

One simple strategy for dealing with screen size variations is to support navigation and zooming over the displayed content: a small screen can provide a configurable window onto a larger information space and, indeed, multi-touch gestures for panning and zooming common on such devices can facilitate access to this content. While this is a valid approach, we argue that is best suited to expert users. The novices typical in seamless learning scenarios may be poorly able to judge the need or value of making viewpoint adjustments to access different parts of an ER. For example, Burigat, Chittaro, and Parlato (2008) investigate how different zooming techniques can facilitate navigation in large information spaces on mobile devices, concluding that overviews can be a useful tool. While this is a useful finding, learners may struggle to make the best use of this kind of complex design feature—Sweller, van Merrienboer and Paas (1998), for example, argue that learners experience "heavy extraneous cognitive load" when required to "mentally integrate" spatially separated instructional materials, such as a windowed view and an overview. This extraneous load negatively impacts learning.

A number of other authors provide evidence to support this claim. For example, Kozma (2003) expands on the differences between experts and novices during their use of ERs. Novices are reported to focus on surface features such as color, motion, and labels that hinder their ability to understand the underlying phenomena of interest. Furthermore, this focus also hinders their ability to establish connections between different representations as surface features of different ERs can vary substantially. Lowe (1996) reinforces this point in a discussion of educational animations, a common form of ER used in technology-enhanced learning systems. Novices' focus on superficial details of the presentation was reported to lower their ability to form accurate mental models of the phenomena of interest. Finally, de Vries (2006) catalogs the difficulties students encounter when constructing different ERs during a design task. The students, learning in pairs, were typically unable to fully understand the implications of using mixed ERs; they were unable to integrate across the different representations.

One solution to this problem would be employed new devices that enable equivalent screens sizes and interactional capabilities across a wide range of learning settings. For example, augmented reality (AR) headsets provide large visual displays in portable form factors. While numerous authors are heralding their ability to revolutionize education (Akçayır & Akçayır, 2017) through display of immersive multimedia content superimposed over and on objects in the real world, the production of empirical evidence to support these claims is an ongoing effort. Furthermore, we note that while these systems feature rich graphical displays, mechanisms for interacting with them are much less well developed. The Microsoft Hololens, a prominent recent AR headset, is controlled via a head controlled cursor and limited set of hand gestures (e.g. select, open menu)—a relatively sparse set of input primitives that does little to extend standard computer input techniques. Furthermore, the compelling nature of AR displays may exacerbate the propensity of novice users to focus on superficial contents over representational fundamentals—AR can distract. Alternatively, learners may overlook underlying abstract concepts by focusing on the "ease" of information manipulation—in some sense, understanding the representation, but not the data it is built on (Scaife and Rogers, 1996).

To sum up, use of different devices in different learning contexts is a core feature of seamless learning. ERs will need to be optimized to match these form factors. However, the literature on ERs also highlights the challenges inherent in moving between representations, specifically identifying novices (a category most learners will fit into) as a group that struggles with this process. Accordingly, we recommend that ERs for seamless learning scenarios are designed to facilitate learners building appropriate connections through techniques such as simplifying designs (e.g., minimal use of animations or interactivity) and relying on readily apprehended features (e.g., color, shape).

4.2 Social Settings and Contexts

The ways learners use material resources, such as ERs, is dependent on factors beyond the design of the resources themselves. The social environment that ERs are deployed in is one such factor; different ERs can be better or worse fits for different social settings and learning contexts. Indeed, distributed and situational learning perspectives applied to collaborative learning scenarios have consistently pointed out that the ways groups of learners appropriate informational resources will influence how subsequent learning activities play out (see for example, Salomon, 1993a; Sawyer & Greeno, 2009). This suggests that collaborative learning activities are influenced not only by the artifacts available for the task, but also by interactions among the learners and expectations regarding group functioning and how resources will be used and managed. For example, if learning resources are centered on a single device, different groups of learners may deploy strategies as diverse as time sharing access among all group members to having one user monopolize use, variations in strategy that have wide reaching impact on group learning outcomes (Sollervall et al., 2012).

Research in various domains exemplifies these points. For example, de Vries (2006) reports on the difficulties experienced by dyads of learners in identifying relevant information in ERs, and in understanding the relationships between different ERs, during completion of a product design task. Similarly, White and Pea (2011) argue that being able to represent a concept in different ways is a critical quality of genuine understanding. However, their review of the literature, and their empirical findings in the domain of mathematics, clearly highlight the challenges learners experience when re-arranging their collaborative practices to leverage different ERs in order to solve increasingly difficult tasks. Learning how to use various ERs collaboratively took time as consistent exposure to related representations was required for learners to understand how they were linked.

Moreover, Fisher, Gräsel and Mandl (2002) discuss two potential problems that can occur during consensus seeking in collaborative learning tasks. Firstly, an inability to reach a common understanding that can even lead to conflict. Secondly, reaching an illusory consensus, therefore masking dissent and failing to achieve learning goals. ERs can influence these knowledge convergence processes—Fischer and Mandl (2005) highlight how ERs can support building consensus in terms of processes (how learners influence each other when engaged in learning) and, to a lesser extent, in terms of outcomes (to what extent learners build up similar knowledge representations as a result of their interactions). Similarly, Otero et al.

(2011) argued that understanding how socio-affective factors influence group interactions will be important in successfully promoting use of context-specific ERs. However, we note that although it is clear that social contexts and specific group characteristics will impact the effectiveness of different ERs, there is currently limited literature providing specific recommendations for optimal arrangements. Surfacing such recommendations represents a key challenge for future research.

4.3 Physical Space and Context

The physical characteristics of a space and the available technological infrastructure influence people's activities by imposing constraints, providing opportunities for action and shaping expectations regarding what can be done (see for example, Harrison & Dourish, 1996; Hornecker & Buur, 2006; Rogers & Rodden, 2003; Rossitto & Eklundh, 2007). Hornecker and Buur (2006) presented an influential framework for reflecting on tangible user interfaces (Ishii & Ullmer, 1997) that are embedded within a physical space and social setting. Two of the four themes they identify are particularly relevant to the discussion in this article: spatial interaction and embodied facilitation. Spatial interaction emphasizes that tangible systems are inherently embodied—in the world—and that using them involves continuous movement in relation to the structural properties of the space, the objects that inhabit it and other people. Embodied facilitation highlights the fact that different configurations of objects can hinder or facilitate particular behaviors.

To understand how these ideas relate to ERs and learning, let us consider a concrete example. Situated digital displays, most typically in the form of fixed screens or projections, are intrinsically embedded in the physical space in which they are located. They act as focal points for information display and facilitate exchanges between online and physical spaces (José, Otero, Izadi, & Harper, 2008; Otero, Müller, Alissandrakis, & Milrad, 2013; Rogers & Rodden, 2003). Rogers and Rodden (2003) analyze how different situated display systems influence the social interactions that occur around them and how this is affected by the spatial configuration of the space they are in; they argue that devices such as small-scale laptop or PC screens, large wall displays and multi-user tabletops support different types and qualities of interaction and collaboration. To highlight the validity of their analysis, they describe the eSpace system for promoting more symmetric interaction between travel agents and their clients by allowing both parties to actively share the display and information it shows.

These ideas directly apply to educational settings, especially collaborative learning scenarios that incorporate non-technological artifacts that can affect learning activities (for example, arrangements of furniture that promote or hinder social interaction). Rossitto and Eklundh (2007), for example, seek to understand "nomadic" learning practices and highlight the effectiveness with which learners were able to "turn locations they travel to into workplaces" (p. 45)—basically to adapt the sites they visit to suit their tasks and meet their needs. Terrenghi, Quigley, and Dix (2009) expand on these ideas. They provide an analysis of the relationships between different types of display, the characteristics of the physical spaces they inhabit, proxemics (Greenberg, Marquardt, Ballendat, Diaz-Marino, & Wang, 2011) and social interaction; this analysis can be directly applied to the design of learning environments in which ERs are displayed to users. However, we also note that the influence of space on ERs is not unidirectional: the presence of particular ERs (e.g. Rogers and Rodden eSpace display) will also impact the types and quality of the activities that take place around them.

Finally, in addition, these issues concerning physical and spatial constraints are substantially impacted by the available technological infrastructure. Previous literature reviews in the seamless learning domain have documented the types and forms of this infrastructure (see for example, Hwang & Tsai, 2011; Wu et al., 2012; Zydney & Warner, 2016), emphasizing the use of mixed platforms such as in-class PCs and out-of-class mobile devices. Other authors have noted this diversity represents a research challenge. For example, Kohen-Vacs and Ronen (2015) present a framework that explicitly addresses the technically multifarious nature of seamless learning systems. Their approach tackles the fragmentation inherent in the use of different technologies to support different stages of the learning activity across distinct contexts. Their solution supports the flow of information along the different components of the system by using a unified data repository and format. Additionally, the data to be consumed, the devices used and the activities proposed are framed by combined pedagogically inspired learning scripts that promote coherence through the learning activity. While we agree that technological fragmentation is a significant problem for seamless learning systems, this paper highlights a parallel need to examine *representational fragmentation*: it is not sufficient for learning materials to be technically integrated; they must also be designed to complement one another from a learner's point of view. With this in mind, the remainder of this paper turns to recommendations for designing ERs to fit seamless learning scenarios.

5 Designing ERs for Shifting Contexts

While prior sections of this article have detailed the inevitability of shifting contexts in seamless learning and the different ways this will impact the perception and use of ERs, it is also important to identify ways to address the potential problems these variations introduce. This section discusses how to design ERs that best fit the seamless learning's shifting contexts by examining three key themes: minimizing the impact of shifting devices and interaction styles; minimizing the impact of discontinuous social settings and; embedded within these two discussions, minimizing the impact changes in physical settings.

5.1 *Minimize the Impact of Shifting Devices and Interaction Techniques*

Different learning contexts are enabled by different device form factors, and a defining feature of many seamless learning projects is activities that involve various platforms. The analysis in this article, however, highlights the challenges inherent in moving between external representations presented on different devices. Variations in screen size from classroom projections through to mobile applications demand radically different visualizations of information. These variations are compounded by differences in the interaction modalities available on different devices: the direct finger-based manipulation common in mobile devices vs the more indirect use of keyboard and mouse on PC platforms. Learners can struggle to understand the connections between content depicted on different devices (Chittaro, 2006) and may also face difficulties in transferring knowledge about how to work with learning contents from one ER/device pair to another.

Therefore, a key recommendation for seamless learning design would be to minimize shifting among devices. A simple strategy for this would be to design a seamless learning activity around a single device form factor that is suited to all of the contexts it is envisaged to operate in. For example, if an activity involves data capture fieldwork in a museum followed by small group work in a classroom, mobile devices can be deployed for both sessions. This will minimize the variations learners experience in form factor and interaction modalities. A less restrictive approach would be to various devices in only one dimension: if multi-touch mobile devices are used in field activities, ensure classroom activities take place using similar multi-touch systems (such as tabletops or some PCs). Another approach in this space would be to repurpose devices to suit different contexts. For example, if mobile devices are used in individual work, then group work could take place by integrating the information contained on each. Imagine a scenario in which each learner acquires spatial field data about a specific location shown as a local map—in a subsequent classroom activity collective data could be reviewed by arranging all the local maps adjacently into a single contiguous space. By using these approaches to minimize the quantity and complexity of device transitions, we argue that seamless learning systems can avoid introducing extraneous detail that acts as a barrier to learning.

While this recommendation is appealing in its simplicity, it may be unachievable in many seamless learning scenarios. In such situations, it is appropriate to apply design guidance from foundational literature on ERs and, in particular, multiple representations. In particular, we highlight dynalinking (Scaife and Rogers, 1996), or the creation of explicit links between representations, that update in real time as a particularly valuable approach. Changes in one representation that result in immediate, observable changes in another can aid learners in establishing core connections between the different ERs. Ainsworth's taxonomy (1999a, b) of the ways in which multiple representations can reinforce each other also provides an important departure point for designs in this space. Given the tendency for learners to focus on surface features over underlying meanings (see for example, Kozma, 2003; Lowe, 1996), we specifically identify developing representations to support abstraction of knowledge as a core target. Ainsworth (1999a, b) suggests this can be achieved by through combinations of ERs that are domain-specific and designed to encourage the construction of connections between them in order to surface the underlying structure of the represented data, to focus on essential commonalities of the underlying domain/concepts and promote further elaborations at a higher level of understanding.

Finally, design principles that emphasize the simplicity of information presentation may also support learners in making connections between representations in order to improve their understanding of underlying concepts. In other words, designers of learning content need to match the type of ER with the information that needs to be conveyed for advancing in the problem space or learning activity. For example, designers should consider avoiding animation when there is no clear added value of providing dynamic content to the information being communicated.

5.2 Smooth Discontinuities Between Social Settings

Transitioning between different social contexts is a key feature of seamless learning environments: individual work is brought to group discussions or group outcomes are processed further in subsequent solo exercises. The tasks, tools, and technologies used in learning activities also inevitably support and foster different types of social interaction: from collaboration to discussion through turn-taking to independent work. As social settings change between learning contexts, learners need to adapt and reconfigure their social roles and use of learning resources such as the ERs that are the main focus of this paper. Accordingly, this section discusses how to design to accommodate the impact of changes to the social setting of a learning context on the use of ERs.

One critical scenario is transitions between individual work and group work. While working alone learners commonly construct, customize or interpret the ERs they work with. When moving to a collaborative setting, they must undertake work to explicate their ERs to the group and also to understand the ERs created by others in order to generate a common understanding. Learning environments and activities should be structured to smooth the passage of the potentially idiosyncratic ERs generated by individuals to more uniform collective versions. To help achieve this, it may be beneficial to profile learners according to their representational preferences, so that users with similar approaches (and individual ERs) work together—to lower the cognitive distance between group members. Alternatively, group work can impose predetermined ERs that individuals must map their own creations to, ensuring the validity and correctness of the shared ER. To aid this process, careful linking mechanisms should be designed that highlight commonalities and differences between the central ER and an individual's own design. This could be complemented through discussion and commentary activities that explicitly focus on the differences between ERs generated by each of a group of learners. Dissecting the ERs of others will not only aid in developing a shared understanding but, via processes such as abstraction, may also help learners better grasp the core concepts underlying an ER. A similar design strategy can be deployed in moving from centralized group representations used in collaborative learning to individual activities—as representations are used and customized by an individual, the impact of the changes should be highlighted. This could be achieved by capturing when representational changes are made and prompting learners to reflect on their impact and value.

Social changes are also inherent during transitions from outside classroom learning activities (or less formal contexts) to classroom activities and vice versa. Even when groups remain identical, the dynamics of their interaction will change based on the social affordances and norms of the physical context and thus impact how they use ERs. For example, in unsupervised outdoor settings, a group's behavior might most closely resemble that of play. The group's management of ERs (and other resources) in such a situation would differ substantially from that in a formal, supervised classroom setting. Once again, one possible solution to these variations is stability: maintain teams and social settings as constant as possible. Another is to focus explicit effort on what Cox (1999) terms representational literacy, or teaching learners about ERs and how to use them. If learners are instructed how to match their collaborative activities with particular ERs, then we can better ensure they are used appropriately to enhance learning.

6 Methodological Challenges When Evaluating Seamless Learning Scenarios from an ERs Perspective

The bulk of this article has been devoted to introducing and expanding on the idea that the use of multiple ERs is inevitable in seamless learning settings that span different technological platforms, social settings, and environments. It has sought to document the challenges inherent in making such shifts and highlight strategies that may help researchers and designers appropriately address these issues. In essence, it applies findings from one area to the day-to-day realities of the other; research findings from studies of ERs are interpreted in terms of the inevitable consequences of seamless learning's shifting contexts. The final part of this review seeks to surface fundamental challenges to future research that might more directly combine these areas—how ER research questions could be addressed by the seamless learning research community.

We group these challenges into three main areas: scope and objectives; capture of transitions; and assessment of learning outcomes. In terms of scope and objectives, we isolate a core tension between scientific approaches and applied interventions. On the scientific side, research on ERs is typically theoretically driven, often laboratory-based and limited in its metrics and objectives (e.g., using task completion times or error rates as a window onto cognitive states). On the applied side, the seamless learning research is, arguably, technology-driven. Evaluations take place in field settings, such as classrooms, and metrics are focused on outcomes such as learning and/or retention rates. Bridging between these settings and styles is a major challenge for future research combining these areas.

In terms of capture of transitions, this represents the central idea in this article—that transitions between learning contexts demand transitions between ERs. Any study that seeks to explore ERs in seamless learning needs explicitly manipulate, control, and record both types of transition. Only by knowing when learning contexts change will researchers be able to provide specifically targeted ERs. Equally, teasing apart relationships between ERs will require tight control of when different versions are exposed to learners. Managing these transitions might be as simple as strictly segregating activities and associated ERs into those for fieldwork and classroom (Sollervall et al., 2012) or as complex as tightly interleaved use of multiple contexts and ERs in single sessions (de Vries, 2006). While tracking such transitions is inherently complex, we argue that many technological solutions can be leveraged to capture fine-grained interactions suitable for this purpose. For example, smart pens such as the Anoto system (http://www.anoto.com/) can log written text with high fidelity, supporting analysis of how students engage with print representations. Equally work on tangible user interfaces (Ishii & Ullmer, 1997) has been applied to learning environments (Marshall, 2007)—interaction with such systems typically occurs via manipulation of precisely tracking physical objects. The data generated can support detailed analysis of behaviors. We believe that future work should explore the integration of this kind of high fidelity tracking to yield data that supports experimental examinations of the impact of specific ERs on learning performance in seamless learning contents.

Finally, assessing the impact of learning outcomes due to ERs will be particularly challenging; while a host of existing studies have demonstrated the benefits of ERs in relatively controlled settings (e.g. Scaife and Rogers, 1996), the more complex real-world contexts of seamless learning will make replicating and extending findings highly challenging. Effective strategies to mitigate these problems would include tightly compartmentalizing learning assessments by, for example, establishing and assessing fixed learning goals for each transition. Rigorous studies that use such techniques to address the evidential gap between laboratory-based concepts and the real-world learning environments are an important next step for research linking ERs to seamless learning.

7 Conclusions

This chapter examined seamless learning from the perspective of external representations. It considered issues related to: the form factor of the devices and how this affects their interactional qualities; the need to understand the social settings and corresponding contexts; and the physical space. It seeks, firstly, to establish the relevance of ER literature and perspectives to the topic of seamless learning and, secondly, to elaborate on the key themes, tensions and research directions that emerge from their combination. We argue that the design and evaluation of next generation seamless learning seamless systems needs to move beyond technological concerns to also include a focus on fundamental theoretical issues—the representational perspectives outlined in this paper are one such focus. More specifically, we have also shown how insights from ER research can be applied to seamless learning scenarios in terms of both the intrinsic challenges this poses and via recommendations that can guide researchers and designers toward viable solutions. The chapter closes by reflecting on the methodological issues that researchers will face when incorporating an ERs perspective into empirical evaluations of seamless learning systems. By broadly outlining the implications of applying ER perspectives to seamless learning design and research activities, we hope to contribute to developing a theoretically derived foundation that can support the design, development, and evaluation of future systems.

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Chapter 4
An Inspiration from Border Crossing: Principle of Boundary Activity for Integrating Learning in the Formal and Informal Spaces

Daner Sun and Chee-Kit Looi

1 Introduction

Regardless of how it is defined, learning in informal spaces has a variety of cognitive, affective, social, and behavioral effects that can make a significant contribution to learning (Morag & Tal, 2012). Research findings in science showed that learning experiences in informal spaces could facilitate the acquisition of scientific concepts and the development of inquiry skills, as well as stimulate motivation. Educational documents (e.g., curriculum standards) also endorse teaching and learning practices in informal spaces (NRC, 2009). Although a number of programs or projects have been conducted in either formal or informal spaces or both, few of them have reached good balance in focusing in both learning in and out of classroom. Nowadays, the ubiquitous use of mobile technology creates various opportunities for supporting learning in informal spaces, but the record of best practices on productive interaction between the two learning contexts is limited in terms of curriculum design and implementation. Meanwhile, the combination of learning in formal and informal spaces is one of the design principles for seamless learning (Wong & Looi, 2011), and there are already some proposals and theoretical viewpoints on discussing the connection of learning in both formal and informal spaces (Otero et al., 2011; Wong, Chen, & Jan, 2012). While there are also learning scenarios reported for guiding the seamless learning design (Looi et al., 2009; Sun, Looi, & Wu, 2016a, Sun, Looi, Wu, & Xie, 2016b), more in-depth work are needed to probe the theoretical underpinnings.

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Moreover, with the rising of public awareness of the need for science, technology, engineering and mathematics education, STEM initiative has far-reaching impact on the current schooling system across countries. STEM is an acronym for science, technology, engineering, and mathematics. In many countries, STEM education has permeated from primary to university levels with aims of preparing students with competent STEM professional for future career and improving the nation's competitiveness in the global economy (NRC, 2011). In Hong Kong, STEM education is promoted with a key emphasis in the ongoing renewal of the school curriculum development (Education Bureau, 2016). However, poorly principled learning design and implementation of STEM-based activities become the factor that affects the quality of STEM education (Kim et al., 2015; Nadelson et al., 2013; Nugent et al., 2015). More effort is needed to improve STEM education through integrating it with the informal learning context, which further facilitates students' engagement in STEM activities. Here, we propose to involve learning in informal contexts into STEM education in seamless way guided by BABL principle for informing the relevant studies.

To address these, we propose the principle of boundary activity-based learning (BABL) that extends formal learning into informal settings with the use of mobile technologies under the notion of seamless learning. Part of the BABL principle has been published (Sun & Looi, 2017). The paper will focus on the conceptualization of boundary activity as a connection for tightening the linkage between learning in informal and formal learning spaces in the seamless learning context. The BABL design elements and scenario will be discussed. We hope that this will inspire relevant studies that seek effective learning design and implementation for seamless learning related to border crossing contexts.

2 Literature

2.1 Science Learning in Informal Spaces

Studies showed that the more students are exposed to informal contexts, the more benefits students would gain (Gerber, Cavallo, & Marek, 2001). The transformational role of learning in informal spaces has been well documented in science education. The NRC report argued that informal learning practices are critical for students to learn about the natural world and develop important skills for science learning (NRC, 2009). The Next Generation Science Standards (2013) call for a deeper understanding and application of content to develop high levels of cognition in students through the practice of science. In science, students are engaged in informal learning spaces through communicating, exploring, and understanding science in museums, science centres, botanical gardens, zoos, and field centres, etc. However, the seamlessly connection and communication of the learning between informal and formal spaces are less noticed.

In an earlier time, Hofstein and Rosenfeld (1996) contended, "it would be useful if science educators would consciously utilize a wide range of out-of-school environments which foster science learning." They believed that future research in science education should focus on how to effectively blend informal and formal learning experiences in order to significantly enhance science learning. Bell, Lewenstein, Shouse, and Feder (2009) shared the same viewpoint that informal learning contexts should be taken as complementary to formal schooling rather than as in competition with it. They proposed the greater coherence of informal environments and K-12 classrooms. In summary, the coherence and interaction of learning between formal and informal spaces are necessary for science education. The learning experiences in the informal spaces will not only the value add on the formal learning, but also constitute a unique contribution to science teaching and learning. Thus, no matter whether it is science or other subjects, the quest for the medium for connecting learning in formal and informal spaces is always the frequently discussed topic. Below we review the literature and highlight the representative ideas for this effort.

2.2 Connecting Formal and Informal Learning

With the advance of the Information and Communication Technology (ICT), mobile devices (e.g., smartphones, tablets, handheld science sensors) have been absorbed into the fabric of our daily lives rapidly (Merchant, 2012). Wireless, mobile, and ubiquitous technologies provide learners with the opportunity for more personalized and autonomous seamless experiences across learning contexts (Suáreza, Spechta, Prinsenb, Kalza, & Terniera, 2018; Thüs et al., 2012). Relevant studies have demonstrated that features of mobile technologies could well serve science learning taking place in informal contexts (Looi, Sun, Wu, Seow, & Chia, 2014; Sharples et al., 2014; Song, Wong, & Looi, 2012), and it can provide additional means to promote fruitful constructions of knowledge across time and space, and foster connections between learning experiences (Otero et al., 2011).

According to Hwang and Tsai (2011), despite the multiple definitions of mobile learning, each focusing on a different aspect, they all share the same idea; that is, the mobile device plays an important role in the learning activities no matter whether the activities are conducted in the field or in the classroom. Mobile technologies together with the appropriate pedagogy have been gaining popularity as a tool for facilitating students' learning in informal spaces (Ahmed & Parsons, 2013; Rogers & Price, 2008; Song, 2016; Sun, Looi, & Wu, 2016a, Sun, Looi, Wu, & Xie, 2016b). However, as Sharples, Sánchez, Milrad, and Vavoula (2009) mentioned early on, that an instructional design theory for mobile learning has not been fully articulated. In reviewing the published reports, while most were about creating a learning environment for leveraging the affordances of mobile technologies, the learning experiences they supported were short-term and practice-oriented rather than theory building in intent. Although few researchers have worked on conceptualizing sustainable learning with mobile technologies via establishing coherent and solid connection between formal learning and learning in informal spaces through curriculum design and development, there have more discussions about the medium on connecting these two learning contexts in the field of seamless learning enabled by mobile technologies. Below presents the representative ideas on the connection of two different learning contexts in seamless learning.

When Otero et al. (2011) were discussing the challenges in designing seamless learning scenarios; they mentioned that the effective scenarios can facilitate the establishment of connections between concrete and hands-on experiences, formalisms, symbolic representations, and semantic concepts across different learning situations outside and inside the classroom. They proposed and emphasized the contribution of the external representations (ERs) on connecting the abstract knowledge and learners' experience in the real world, which represents the structure and knowledge of the world, and usually is in the form of physical symbols, objects, external rules, or embedded relations in physical configuration (Zhang, 1997). They summarized that ERs have an impact on how people collaborate, co-construct knowledge, and organize their learning experience. For seamless learning, the ERs would particularly affect students' learning experience in and out of classroom, and vice versa. Therefore, the generation of ERs provides opportunities for students to apply knowledge learnt in different contexts.

Zhang's study focused on students' knowledge building through sustained inquiry and interaction crossing communities based on the use of idea of thread syntheses. He discussed fostering the crossing community interaction for sustained knowledge building which is a new challenge and opportunity for collaborative learning research (Zhang, Bogouslavsky, & Yuang, 2017). He proposed synthetic boundary objects which take the form of idea thread syntheses framed using shared structures of inquiry in a system, namely Idea Thread Mapper. In this case, the Idea Thread Mapper is the medium of connecting learning among different communities, and the idea thread syntheses can trigger students' deep thinking and reflection from different communities/classroom (Zhang et al., 2018).

When studying the seamless knowledge building supported by mobile devices, So et al. (2009) refined artifacts as mediating tool for knowledge building, which created in the forms of locative content: videos, audios, images by the use of mobile technologies (out of classroom) and can be used for triggering knowledge co-construction and collaborative discourses in another context (in classroom, Knowledge Forum). Wong et al. (2012) further emphasized the roles of mediating artefacts for facilitating learner's effective transitions between scenarios (Looi et al., 2009; Wong et al., 2012). Four types of artefacts are identified:

(1) subject matter artefacts (textual information, multimedia files, etc.);
(2) physical artefacts (physical or environmental tools);
(3) socio-cognitive artefacts/non-physical artefacts (teacher's verbal scaffolds, peer discourses);
(4) outcome artefacts/students' generated artefacts (photographs, test, comments, text, etc.).

The seamless learning process can be described as the interaction between learners and these artefacts across time and locations.

In summary, these representative ideas share the same viewpoint that there should be some boundary objects for tightening the linkage between formal learning and learning in informal spaces. In the seamless learning context, the value of boundary objects cannot be neglected. In our opinion, the highlight of boundary objects will address the challenges of learning design in seamless learning context and contribute to the theories of seamless learning. Therefore, we conduct a literature review for elaborating the conception of boundary objects in the field of seamless learning. We will further identify the key elements of learning design based on boundary objects, elucidating the learning design and implementation for seamless learning guided by boundary activity-based learning (BABL) principle.

3 Theoretical Foundations

3.1 The Conception of Boundary Object

Boundary object refers to the common idea generated in the scientific work that needs cooperation among divergent viewpoints and the need for generalizable findings (Star & Griesemer, 1989). It can be either abstract or material, for example, field notes, specimens, and museums, which can be the connections between formal learning and learning in the informal space. Wenger (1998) provided more elaborated ideas that boundary object is one type of the connections between communities of practices, and it is artifacts, documents, terms, concepts, and other forms of reification and around which communities of practices can organize their interconnections. Zhang, Bogouslavsky, & Yuang, (2017) agreed with the conception and he discussed the roles of boundary objects in mediating cross-community interactions.

Akkerman and Bakker (2011) discussed the conception of boundary objects as "organic arrangements that allow different groups to work together, based on a back-and-forth movement between ill-structured use in cross-site work and well-structured use in local. Hence, they are a means of translation within a situation of multisite work relations and requirements." Boundary objects tend to be invisible or taken-for-granted mediations that translate across sites but, when carefully considered or opened up, may provide learning opportunities (Williams & Wake, 2007; Akkerman & Bakker, 2011). This suggests that the form of boundary object can be either invisible or visible, and in an abstract or in a physical way. The latter one is the most frequently discussed as mediating artefacts or external representations. For example, Tsurusaki, Calabrese Barton, Tan, Koch, and Contento (2012) create "transformative boundary objects" and explore how the transformative boundary objects work in teachers' teaching practices with the aim of engaging students' in science learning. They summarized three types of boundary objects: bar graph, scientific research questions, and scientific concept: nutrition in the teaching of healthy food. When integrated with the use of mobile technology, there will be more forms of visible boundary objects such as concept maps, drawings, photographs, videos, and notes generated by mobile tools.

Boundary objects can take the form of abstract concepts introduced in the classroom and elaborated outside the classroom; it can be a guiding question related to a key concept requiring students to do a series of activities to answer it; it can be an event or science phenomena, which require students' investigation outside and discussed in the class. On the other side, the dialogical interaction involves shared key ideas, incidents, comments, concepts, solutions, phenomena, etc., can be the medium of invisible/abstract boundary objects. For example, in Zhang's study, the Idea Thread Mapper is used for capturing the invisible boundary objects (i.e., key concepts, terms, key ideas, comments) in the form of idea thread syntheses (Zhang et al., 2017). In Gilbert and Priest's (1997) study, to link the learning experience in museum visits with the topics learned in the classroom, student group activities focused on discussing the "critical incidents" during the visits. In this case, "critical incidents" can be identified as the invisible boundary objects generated in the museum visits. This invisible boundary object connects students' experiences in museum and their follow-up discussion in the classroom.

3.2 The Principle of Boundary Activity-Based Learning

(1) Boundary activity

Aikenhead and Jegede (1999), and Aikenhead (2001) expressed their ideas based on the viewpoint from cross-cultural science education, which using cultural differences in explaining students learning behaviors in different learning contexts. They acknowledged the cultural broader crossing that most students experience varying degrees when moving from their lifeworlds into the world of school science, so that learning science is a cross-cultural event for most students. The process of dealing with cognitive conflicts arising from culture clashes is the way in which students make sense of their learning in and out of classroom. The research shows that the smoother the transitions of cognition between different learning contexts, the better their academic achievement can be. The quest for the design of boundary object will help students to minimize the difficulties in making these learning transitions. If seamless learning is well designed in addressing the generation of boundary objects in different forms, the external representations, idea thread syntheses, artifacts, mediating artefacts and its related conception, ideas, discussion can be the good representatives of boundary objects for connecting learning in formal and informal spaces. Actually, the learning design based on boundary objects is not just about the design for generation of boundary objects but the identification of different forms of boundary objects and the judgment the roles of these boundary objects play in coordinating the learning taking place in formal and informal places.

In the learning design, Kisiel (2014) proposed that joining resources from both formal and informal learning settings is an effective strategy that enhances students' interest in learning. He coined a term "boundary activity" to define the activities that connect schools and informal science institutions. The boundary activity refers to "those encounters between schools and informal science spaces that involve some kind of designed program-field trip, outreach, and teacher workshop with specific educational objectives." Therefore, boundary activity is a deeper, practice-based interaction between the two communities. Based on the above ideas, we define the boundary activity as the learning activity that takes place in either formal or informal contexts and contains at least one boundary object that mediating learning in formal and informal environments. To facilitate learning in crossing contexts/communities, the design of boundary activity is proposed.

There has been some consensus in the literature on the design of boundary activities, with most of them in agreement on the need to design structured learning activities and conduct sequential activities connected to the formal learning. Research demonstrated that if field activities were "properly conceived, adequately planned, well taught and effectively followed up," they could offer "learners opportunities to develop their knowledge and skills in ways that add value to their everyday experiences in the classroom" (Patrick, Mathews, & Tunnicliffe, 2013; Rickinson et al., 2004). Sharples et al., (2014) proposed to employ scripted learning methods to conduct outside inquiry activities, in which the teacher initiated a structured activity with the use of mobile devices inside the classroom, and then continued it outdoors. DeWitt and Osborne (2007) proposed the key elements of the learning design principle in informal contexts which indicate that the boundary activity can be located either in the formal spaces or informal spaces. It should be fit into appropriate pedagogical principles across formal learning and learning in informal spaces and serve for attaining the same learning objectives.

(2) Components of Boundary Activity

Based on above literature review and CECD's definition of formal learning (OECD, 2008), we propose three components of the design of boundary activity in the formal learning context: boundary object, structure, and learning objective. We further refine the idea to delineate between boundary object, activity structure, and learning objectives: (1) The boundary object is the key component for designing the boundary activities. It acts as a knot that serves as bridging learning in and out of the classroom and capturing the learning process in the informal spaces. The learning design should enable the generation of visible and/or invisible boundary objects, this will probably ensure students' cognition transition between formal and informal learning spaces smoothly. (2) Structure: The boundary activity is conducted in the pre-, during, and post-activity pattern to guarantee the continuum and stability of cognition or skills developed across the learning contexts.

(3) Learning Objective

The learner's explicit objective is to gain knowledge, skills, and/or competences, and develop attitude. The learning objectives of boundary activity should be defined based on the curriculum standard and the characteristics of the contextual variables in practice.

(4) Principle of Boundary Activity-based Learning

Therefore, we propose the principle of boundary activity-based learning (BABL), which encourages the teachers to design seamless learning with considering the involvement of three components of boundary activities. Figure 1 shows the boundary interaction in BABL seamless learning contexts. Learners generate the boundary objects in either visible form or invisible forms. These boundary objects coordinate the knowledge and skills applied in formal and informal contexts. For the teacher, they are responsible for guiding and making use of these boundary objects with the aims of reducing cognition conflict during the transition between two learning contexts. There may be in several ways: (1) designing mobile learning activities for generating visible boundary objects (i.e., learning artefacts); (2) making use of worksheets, assessment, reflection journals for capturing students invisible boundary objects (i.e., reflection, ideas, comments, understandings); (3) relying on technology for representing students' invisible boundary objects (i.e., ideas, understandings). The effective use of boundary objects depends on the organization of the pre-, during and post-boundary activities that happen in different contexts.

To promote the better boundary crossing, there will be four learning mechanisms for constituting the learning potential of boundary crossing mentioned in Akkerman and Bakker's paper (2011): identification, reflection, coordination, and transformation. The mechanism of identification describes how boundary crossing results in

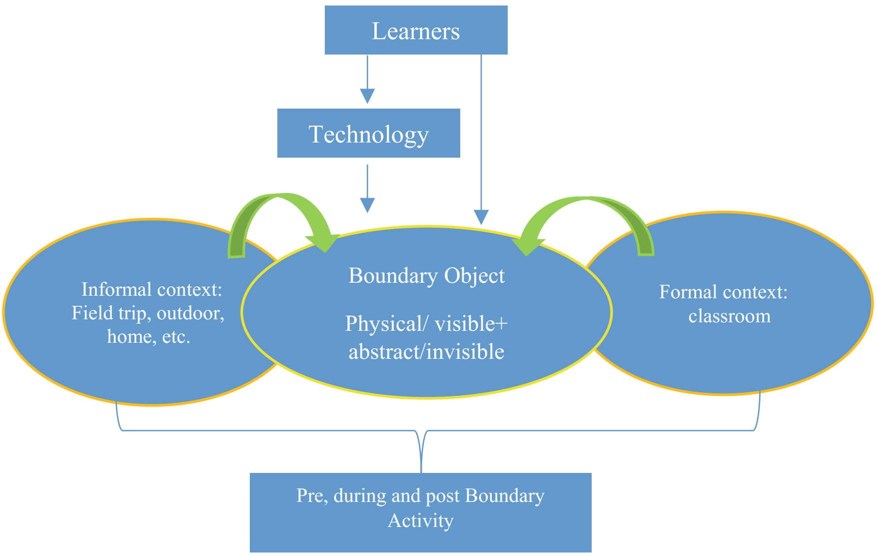

Fig. 1 Boundary interaction between learning in formal and informal spaces

questioning one's core identity which, in turn, leads to a renewed sense-making of different practices and the reconstruction of identities. With the coordination mechanism, centrality is placed on the means, such as mediating artefacts, and procedures that enable efficient cooperation in distributed work. Thus, the central aspect of coordination is overcoming boundaries and providing continuity in the movement across different sociocultural sites. Crossing sociocultural spaces can also facilitate mechanisms of reflection, i.e., make explicit differences between practices and learning something new about own and others' practices. The fourth learning mechanism is transformation, i.e., the profound change of practices or the creation of new ones by means of boundary crossing (see Akkerman & Bakker, 2011). These learning mechanisms remind us that the design and implementation of boundary objects does not only generating, capturing, and evaluating these boundary objects, but how to make use of these boundary objects followed by these mechanisms. To recognizing different identifies in different contexts is the perquisite of learners to carry out different tasks followed by different rules. This will improve work efficiency and quality. Reflecting upon learning in two different contexts will better connect learning experiences, knowledge and skills in formal and informal contexts. Importantly, coordination learning in formal and informal spaces with discussing boundary objects is one of the key mechanisms for BABL seamless learning. Transforming learning is our final target for students' learning in crossing learning spaces. These learning mechanisms remind teachers to pay heed to the nature of the boundary objects, the role that boundary objects play in the different learning contexts, and the learners' levels for achieving the cohesion of formal learning and learning in formal spaces.

4 BABL Guided Seamless Learning: Case Study

4.1 Mediating Tools of BABL Seamless Learning

In BABL seamless learning, theories of curriculum development have been consulted to define and refine the key elements of BABL activities. Van den Akker concludes 10 components of the curriculum: rationale or vision, aims and objectives, content, learning activities, teacher role, materials and resources, grouping, location, time, and assessment (Thijs & van den Akker, 2009). In BABL seamless learning, the instruction of the content knowledge is organized and guided by the pedagogical principles of collaborative inquiry, seamless learning, and mobile learning (Wong & Looi, 2011).

Meanwhile, mobile tools incorporating inquiry learning tools are used as the mediating tools in and out of the classroom. In our study, two platforms are adopted: nQuire-it (http://www.nquire-it.org) which facilitates students' inquiry activities in informal spaces, and Schoology (https://www.schoology.com/) as a learning management system that guides students' online inquiry at a step-by-step manner. Figure 2 represents the overall picture of the roles nQuire-it and Schoology play in the BABL.

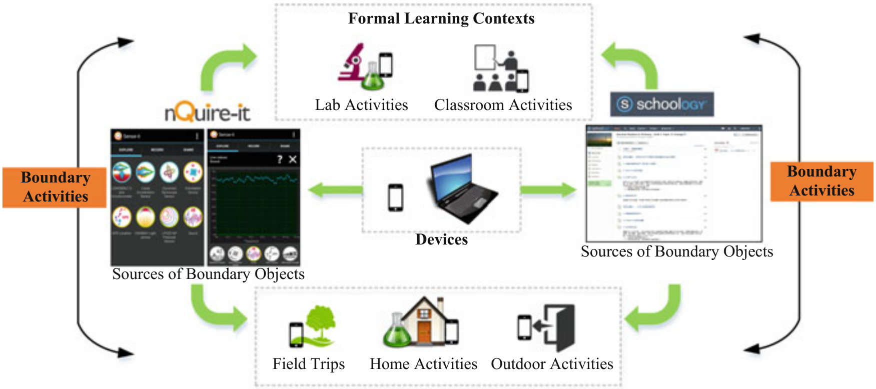

Fig. 2 Combination of Schoology and nQuire-it for STEM education

nQuire-it could support students to collect real-time data outside (i.e., real experimentation, hands-on activities, home activities, field trips) using Spot-it (an app for capturing images and spot things) and Sense-it (a toolkit for collecting science data using smartphone sensors: accelerometer, gyroscope, light, and sound, etc.), and share data and comment data.

Figure 3 shows the data collected using Spot-it, and students describe these pictures on the energy in life that are taken from difference locations. Their classmates review and comment the learning artefacts via clicking: like or dislike, with specific comments on explanation. Thus, the synergic use of nQuire-it and Schoology will offer students rich opportunities to investigate in authentic scientific phenomena to generate the visible boundary objects and to interact with their teachers and classmates any time anywhere, the way invisible boundary objects generated. Here, Schoology and nQuire-it are the main sources of boundary objects. They act as the boundary crossing tools for students' cognition coordination and reflection in different contexts.

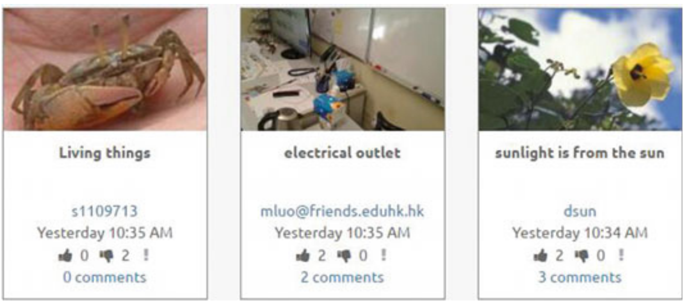

Fig. 3 Data collected by Spot-it as boundary objects

4.2 Lesson Exemplar

The topic: Energy Transformation is from P6 General Studies in Hong Kong. We designed the lessons based on the BABL principle, followed the learning objectives in the textbook and syllabus, and extended the topic into STEM education with embedding an engineering activity: making a solar car. The learning objectives are depicted in Table 1. We emphasize the value of BABL in guiding the learning design in both science and STEM education.

Table 2 is the lesson design with relevant instructions presenting the inquiry learning activities enabled by Schoology and nQuire-it. In this learning design, we emphasize students' self-inquiry and collaborative inquiry guided by Context and Questions, Spot-It Investigation, Sharing and Discussion, Summary and Reflection (Fig. 3). Venues refer to the location of learning activities. Teachers take on the role of guide, collaborator, and mentor. Invisible and visible boundary objects can be generated during inquiry activities guided by the teacher. More specifically, the use of nQuire-it particularly enhances students' interaction with the informal learning spaces for testing their hypothesis and deepening conceptual understanding. In this case, the real-time data in the form of photographs and graphs collected out of classroom and discussed in the classroom are the visible boundary objects. The sharing and discussion, summary and reflection are the main sources for finding the invisible boundary objects. The activities for planning to conduct data collection and follow-up sharing and discussion are the boundary activities. With mobile technology and BABL, teachers have more opportunities to monitor students' STEM process and capture their thinking, reasoning, and problem-solving processes. Guided by

Table 1 Learning objectives in topic of energy transformation

General studies		
Knowledge	Skills	Attitude and value
• List different types of energy • Explain that energy can be transformed from one type to another type • Problem-solving using energy in daily life	Collaborative learning skills, inquiry skills, reasoning skills, self-directed learning skills, ICT skills, and problem-solving skills.	Curiosity, respecting evidence, environment protection
STEM		
Subject knowledge	Skills	Attitude and value
• Science: physics • Technology: nQuire-it, schoolboy • Engineering: making a solar car • Maths: graph reading	Collaborative learning skills, inquiry skills, reasoning skills, self-directed learning skills, ICT skills, and problem-solving skills.	Curiosity, respecting evidence, environment protection, STEM interests and engagement

Table 2 Lesson design of energy transformation

Inquiry activity: the solar power				
Procedure	Teacher	Student	Resources	Proposed venue
1. Context and questions [pre-boundary activity]	Introduction: solar power and its application in life	• Recognize solar power • Form groups • Join the nQuire-it activity: Looking for sunlight • Collect data of sunlight intensity in classroom • Upload data in nQuire-it	Textbooks or other resources	Classroom
2. Spot-it investigation [boundary activity]	Guide and facilitation: explore the of sunlight intensity at in classroom.		Sense-it	Classroom
	Guide and facilitation : to explore the sunlight intensity outside	• Discuss • Explore sunlight in outside spaces using the light sensor • Upload data in nQuire-it		Outside
	Preview/check students' work in the platform		nQuire-it	Any venues
3. Sharing and discussion [post-boundary activity]	Guide: view other groups' work and comment it	• View other groups' plots and descriptions • Make comments on other's work	nQuire-it	Classroom
4. Conclusion and reflection [post-boundary activity]	Guide: share students' reflection and make conclusion	• Communicate (share) with others • Describe learning experience and reflections in Schoology	Schoology	Classroom

inquiry learning model and BABL principle, students' seamless learning become internationally, pedagogically and structurally.

4.3 *Feedback from Students and Their Teacher*

We conducted a pilot study of students' ($n = 36$ students, with age of 11 and 12) in a Hong Kong school in which the teacher led science activities first in the classroom and provided opportunities for the students to experience BABL seamless learning. Positive feedback on the following aspects based on a post-survey was received:

(1) Using Schoology discussion and nQuire-it comment function, 62% of students agreed that the activity made them more collaborative in doing tasks and discussion.
(2) Students were asked whether the out-of-classroom activity is related to what they have learnt in the classroom. More than 65% of students agreed that the out-of-classroom activity is related to the knowledge learnt in the classroom, with 34.4% of them in strong agreement. Moreover, 68% students thought they had good opportunity of elaborating their out-of-classroom learning in the classroom. 57.1% of them strongly agreed with it. 68% of students responded that the out-of-classroom activity improved their thinking and understanding.
(3) Students also responded positively (70%) that they obtained opportunities of knowing that their classmates worked and learned from each other.
(4) 80% of them expressed their interest and motivation in the BABL activities and would like to use the approach in exploring other topics.

In our interview with the teacher who taught the topic, she expressed her enthusiasm on teaching the topic based on BABL principle. She thought it is significant to integrate students' learning in the formal contexts with the learning in the formal contexts. She explained further that students are interested in and excited in doing outdoor activities with mobile devices. Design using the BABL principle makes the activities in and out of classroom more connected, and this makes almost every student be engaged in the out of classroom activities. The teacher saw students are discussing and *collaborating* more in the out-of-classroom activities compare to the previous classes, as students knew they need to conduct peer assessment on each other's work when came back to the classroom. The teacher emphasized that she would like to use the nQuire-it into the teaching of other topics guided by BABL principle.

5 Conclusion

In this paper, we present a literature review that discusses the importance of learning in informal spaces to enhance learning in classroom and the origins of boundary objects. We propose using BABL principle as a framework to design the seamless learning activities in science and STEM education. The principle of BABL is articulated for providing guideline for teachers' design and implementation of science/STEM activities. A lesson exemplar is presented to show the ways of integrating BABL principle with STEM learning activities in pedagogical way. Initial pilot study results have shown that students have positive experiences of BABL seamless learning activities. Moreover, when BABL principle integrated with seamless learning, a learning notion refers to: "the seamless integration of the learning experiences across various dimensions including formal and informal learning contexts, individual and social learning, and physical world and cyberspace" (Wong & Looi, 2011), the seamlessly switching between different learning tasks done in different learning contexts can be better realized. More importantly, the seamless continuation of cognition can be smoothly if boundary activities are well designed and implemented crossing formal learning and informal learning contexts.

Therefore, we could see the potentials of BABL principle for guiding the learning design and implementation in the field of mobile learning, seamless learning, and even flipped classroom which involve crossing learning contexts. It further inspires us that tightening the connection and improving the cognitive interaction between learning in formal and informal spaces, different categories of students' border transitions should be identified (please refer to Students' Ease in Crossing Cultural Borders into School Science in Aikenhead, 1996) and four learning mechanisms of boundary crossing (Akkerman & Bakker, 2011) should be respected. In the further research, more in-depth investigation will be conducted for exposing the cognition mechanism by the generation of invisible boundary objects in the BABL guided seamless learning in the field of science and STEM education.

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Part II
Architectures and Technologies for Supporting Seamless Learning

Chapter 5
Towards an Architectural Approach to Supporting Collaborative Seamless Learning Experiences

Dan Kohen-Vacs, Marcelo Milrad and Marc Jansen

1 Introduction

Over recent decades, there has been increasing interest among researchers and educators in the design and practice of educational activities that enable opportunities for collaborative learning. Growing interest is currently being shown in activities offering new educational opportunities that are exploitable across contexts and settings, including those that can be exercised in various social settings, anywhere and at any time. Teachers and students can exploit these new opportunities for innovative and educational experiences, using various Web and mobile technologies as a means of supporting innovative modes for their educational interactions (Huang & Chiu, 2015). These types of educational activities demand deployment efforts that emphasize the challenges related to the design and implementation of these types of educational activities, executed seamlessly across contexts and settings.

Communities of researchers and practitioners recognize the opportunities that are emerging due to the special nature of these activities, including their richness of context and settings that provide teachers and students with new opportunities to benefit from authentic learning experiences wherever and whenever available.

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In addition, these communities also acknowledge the challenges they would need to overcome in the design and deployment of activities with these characteristics (Baran, 2014; Osang, Ngole, & Tsuma, 2013; Sharples, 2013).

Our ongoing research focuses on approaches enabling the transformation of learning requirements into mature design and deployment for educational activities, which can later be shared and reused (Kohen-Vacs, 2016; Kohen-Vacs, Milrad, Ronen, & Jansen, 2016). Specifically, we address various types of actors, including the designers and users (teachers or researchers) required for certain aspects of these activities, and including the physical location in which they are conducted, the time at which they are conducted and the social organization of their participants. No less important is our emphasis, shared with other researches, on the variety of learning opportunities and the best ways to enable teachers and students to interact with them during these activities (Al-Emran, Elsherif, & Shaalan, 2016; Muñoz-Cristóbal, Asensio-Pérez, Martínez-Monés, & Dimitriadis, 2015).

These considerations illustrate the complexity of these activities and emphasize the role of the technological means necessary to alleviate the abovementioned challenges (King, Gardner-McCune, Vargas, & Jimenez, 2014). These aspects of educational activities, including educational, administrational and technological concerns, were explored by Wong and Looi (2011) in their research work focusing on mobile-assisted seamless learning (MSL) dimensions. More recent research published by Milrad et al. (2013) suggests ways in which novel educational design patterns, mobile technologies and software tools can be used to design future educational activities and technological solutions that can support seamless and mobile learning. Prieto et al. (2015) also recognize concepts related to MSL dimensions and consider novel educational interactions. In particular, acknowledgment of such dimensions could be used while intending to support complex interactions by a series of interrelated software components, each offering support for some of the above-mentioned concerns. Furthermore, these components could be conveniently organized in an overall architecture providing comprehensive support for the enactment of these educational activities. Such an architecture should aspire to provide an optimized, meaningful and seamless experience for teachers and students during their educational experiences (Kohen-Vacs et al., 2016).

In this chapter, we describe our ongoing work to design, develop and deploy different software solutions to support collaborative seamless learning activities practiced across a variety of settings. We present our efforts to address the research question of how best to design systems and tools to support students during the implementation of collaborative seamless learning activities.

We therefore describe three learning activities that we designed, developed and deployed. In the next section of this chapter, we describe our approach, which enables researchers and teachers to consider the design of learning activities that are intended to be seamlessly practiced across contexts. Following this, we suggest an architecture that is inspired by our implementations and is intended to support such activities while focusing on interactions that can take place across contexts and settings. Our proposed architecture contains various types of modules and software components that are capable of supporting various modes of interactions, whenever and wherever required by students, and which can be socially organized in various settings. In this way, we show how the main features required to support collaborative seamless learning, such as flexibility, expansibility and reuse, are constructed in the proposed architecture. More specifically, we discuss Web and mobile technologies, and other components offering support for existing and new types of educational interactions to be designed and deployed. We also consider these exciting and emerging interactions in terms of the ways they interrelate within these activities. In particular, we discuss various types of interactions in terms of the interoperability features required in activities performed across different contexts and settings. Finally, we present our conclusions and describe directions for future work.

2 Towards Collaborative Seamless Learning Across Contexts

As mentioned previously, mobile seamless learning involves special features, in the sense that it can be practiced across contexts and in various settings. In this section, we will specify and elaborate on these types of activities, while emphasizing the richness of options opening the way for potential opportunities to implement innovative collaborative learning activities. In addition, we will highlight the challenges faced by researchers and teachers when considering a process that includes the design, development and deployment of these types of collaborative and seamless learning activities.

In Fig. 1, we illustrate a process that can be started by various types of actors or stakeholders, including researchers and/or teachers exploring functional requirements for educational activities to be practiced across contexts (Kohen-Vacs, 2016). In this sense, we argue that the process illustrated here is adapted to the nature of such activities, since it provides opportunities to consider, evaluate and evolve a set of interwoven specifications that can later be implemented as interrelated interactions to be exercised across contexts.

The initial step in the process illustrated above can be repeatedly evaluated, until stakeholders decide to transform the identified requirements into practical designs.

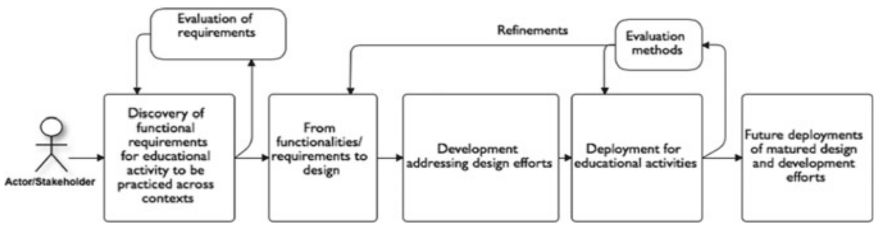

Fig. 1 Design and deployment efforts towards collaborative and seamless learning activities to be practiced across contexts

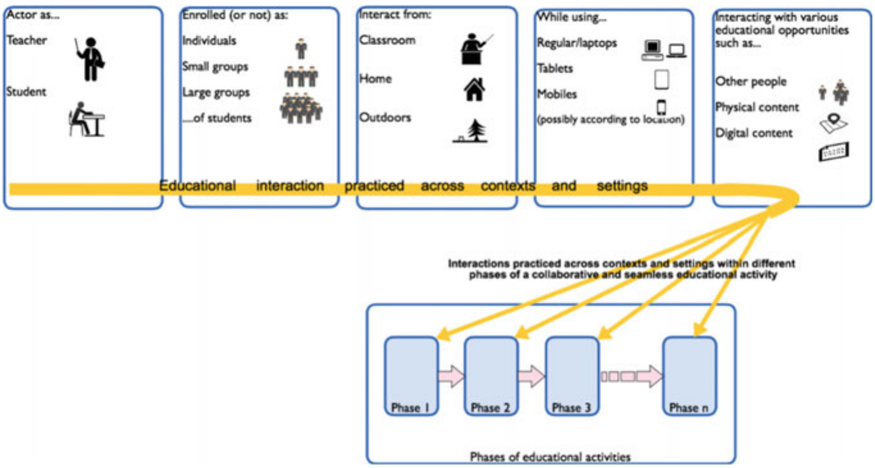

Fig. 2 Educational interactions executed within phases of collaborative and seamless activities

In the next step, these design efforts move into the developmental stage, followed by deployment through the implementation of educational activities. These two steps could also be evaluated using several iterations, for further refinement. Eventually, this process matures into design and development efforts that can be offered to researchers, teachers and students in future educational activities. In Fig. 2, we show the possible options for structuring and enacting collaborative and seamless learning through practices exercised by teachers and students, organized in various settings. In addition, these interactions could be conducted from several locations and supported by different types of technological devices and tools. Students could interact from anywhere at any time, with digital content stored in the cloud and deployed by their teachers as part of a pre-planned educational path. Alternatively, they could interact with objects that emerge during the enactment of these activities, which can be used as new and appealing educational opportunities (De Jong et al., 2010).

The figure above shows an educational activity involving various actors (stakeholders), including teachers and students, and illustrates how they participate in an orchestrated activity consisting of multiple phases. In addition, we demonstrate that their participation in each of these phases may involve interactions while enrolled in different social settings (individual and small/large groups). They may participate in this activity from several locations offering educational opportunities. During participation, they use various technological devices to support their educational interactions. Finally, it should be mentioned that teachers and students can interact during these activities with their peers, with physical content found in their location or with digital content accessible via their technological devices.

The practice of these educational activities has been extensively described by the research community, including by Spikol and Milrad (2008) and Zurita, Baloian and Frez (2014). In some cases, students have used technologies that aimed to facilitate interactions across contexts. Mobile and other Web tools have been exploited to make interactions more continuous and seamless, while aiming to provide a learning flow.

As described in our previous research work, we designed and deployed activities reflecting computer-supported collaborative learning (CSCL). These deployment efforts were implemented across contexts and settings, and required the design and development of a process fostering seamless learning (Kohen-Vacs, Ronen, Ben Aharon, & Milrad, 2011; Kohen-Vacs et al., 2016; Spikol & Milrad, 2008). In a previous research study, we consolidated and addressed the combination of CSCL and SL as collaborative seamless activities (CSL) activities (Kohen-Vacs, 2016).

The design and development process of CSL activities includes opportunities related to a learning process that is potentially rich in terms of its content and the type of interactions that can be practiced from real settings. These opportunities should be examined in the light of both the advantages they offer and the challenges involved. For example, the organizational aspects of CSL activities, including the temporal line of enactment, places of practice and social settings, present the designers of such activities with challenges that are recognized by the research and teaching communities. Furthermore, in some cases, these challenges discourage communities of practitioners from implementing such educational activities. In view of this, intensive efforts are currently being made to alleviate these challenges using technological tools that offer a convenient means for facilitated interactions. Equally important are the educational aspects that should be considered when adopting and implementing technologies for such activities. In general, the educational content should be adapted for digital use, in order to maximize its pedagogical potential. Consequently, we find that opportunities and challenges related to the deployment of CSL activities can be examined in the light of three main aspects drawn from MSL dimensions: the educational, organizational and technological aspects (Wong & Looi, 2011). We acknowledge these aspects and dimensions in the light of our research efforts exploring CSL activities, as discussed in our research aims in the introductory section.

In the next section, we present a sample of three activities we designed, developed and deployed with the aim of providing teachers and learners with CSL activities. These three activities are described, including their opportunities and challenges, since we later use them as exemplary cases resulting from the design approach proposed here. In a later section, we suggest an architecture based on this design that enables their deployment in real settings. We also show that these three activities share many similarities in terms of their educational aspects, administrative challenges and the technological means used to support teachers conducting these with their students.

In the next section, we present some of the efforts we have made to enable collaborative seamless learning across contexts and in various settings. The process of designing, developing and deploying mobile learning should be carried out while taking into consideration the different dimensions related to individual and social learning, as well as the geo-temporal aspects of the learning situation and the models of interaction (physical, virtual and a combination of both) (Muñoz-Cristóbal et al., 2015; Pea et al., 2011).

3 CSL Cases

As previously mentioned, this section presents three CSL activities that aim to provide a collaborative learning experience across settings with the support of various Web and mobile technologies. We describe and present another activity providing students with the opportunity to become familiar with the usability issues that can be found in their daily lives. We offer teachers and students the chance to participate in this activity as part of a collaborative learning experience carried out using various trajectories across different contexts (Kohen-Vacs et al., 2011). We then describe an activity developed in relation to the Learning Ecology through Science with Global Outcomes (LETS GO) project (Vogel, Kurti, Milrad, Johansson, & Müller, 2014).

Finally, we discuss an activity that aims to enhance educational experiences through the use of interactive videos supported by a Web environment called EDU.Tube, which operates on both regular and mobile devices (Kohen-Vacs et al., 2016).

3.1 Case 1: Usability Issues

This activity aims to familiarize students at the university level with usability topics, using authentic issues encountered on campus. This activity consists of five stages, beginning with an initial activity requiring the student to perform it outdoors using a mobile device. This activity also includes interactions that are exercised across contexts and in various settings, in a manner that requires design and development efforts to consider the MSL dimensions (Wong & Looi, 2011; Wong, Milrad, & Specht, 2015).

This activity includes a phase that aims to provide students with general information about the topic of usability. It also includes a subsequent phase performed outdoors in 10 groups of three to four students. In this stage, students are challenged to tour the campus and to identify usability problems of types identified by them in formal lessons. Students who spot such an issue can use a mobile device to take and submit a picture that represents it. The students are also required to submit a short description explaining the usability issue captured in the picture. In Fig. 3, we illustrate students interacting during the second phase while encountering a usability issue on campus.

The figure above shows two students participating in the course on usability issues, taking part in an activity conducted both indoors and outdoors in order to enable familiarization with these issues. More specifically, these students are pointing out a usability problem found within the outdoor environment of their campus and are taking a picture that includes a geo-tagging (GPS) location and a text explaining the nature of the usability problem. The next phases of this activity are intended to be performed at home via the Web and computers. In the second phase of the activity, members of each group select the best item identified by members of their own group. The third phase focuses on an analysis of the tagging: Each student is presented with four of the usability problems documented by other groups and is asked to select up to

Fig. 3 Students identify a usability issue located outdoors

three tags from a given list that best describe the problem. In the fourth phase, students vote on the most significant issues, as represented by the contributed pictures. In this phase, we aim to engage students through appealing interactions while requesting them to vote for the issue that was best tagged by the participants. The fifth and final phase includes a presentation of the results of the competition and a debriefing by the teacher, based on the information contributed by students throughout the activity. This activity relies on Web and mobile technologies to support the teacher's and students' interactions. We use the MoCoLeS system based on Google XFORMS to support mobile interactions, including their storage in a Web environment. In addition, we use the CeLS environment with related middleware to orchestrate the teacher's and students' interactions taking place throughout the interrelated phases of this CSL activity (Kohen-Vacs et al., 2011).

3.2 Case 2: LETS GO

LETS GO learning activities were deployed as part of an environmental science curriculum and were aimed at students at the K-12 level. In these activities, learners focused on exploring various environmental characteristics, including the quality of the soil and water (woodland ecology) in their neighbourhood. These activities usually include workshops aiming to enable the students to become familiarized with the specific subject matter and central concepts, through ideas associated with the inquiry and learning process (Vogel et al., 2014). The educational interactions carried out across contexts and settings in this activity are illustrated in Fig. 4.

In the figure, we illustrate the various requirements for this activity, including the mobility of students and teachers across the distributed environments offering educational opportunities. In addition, this figure shows the utilization of technologies supporting students' interactions, including the use of various devices communicating with the service-oriented systems responsible for handling users' posts. In particular, these posts deal with data collection and interaction with peers, as part of a collaborative and educational activity.

These activities usually comprised six to eight lessons over a period of five weeks, starting with an introduction to the inquiry process in which the basic concepts of the activity were introduced and students discussed the initial questions given to them about a specific topic (e.g. water quality). A particular LETS GO activity included learning interactions to be carried out across contexts and in various settings, in a

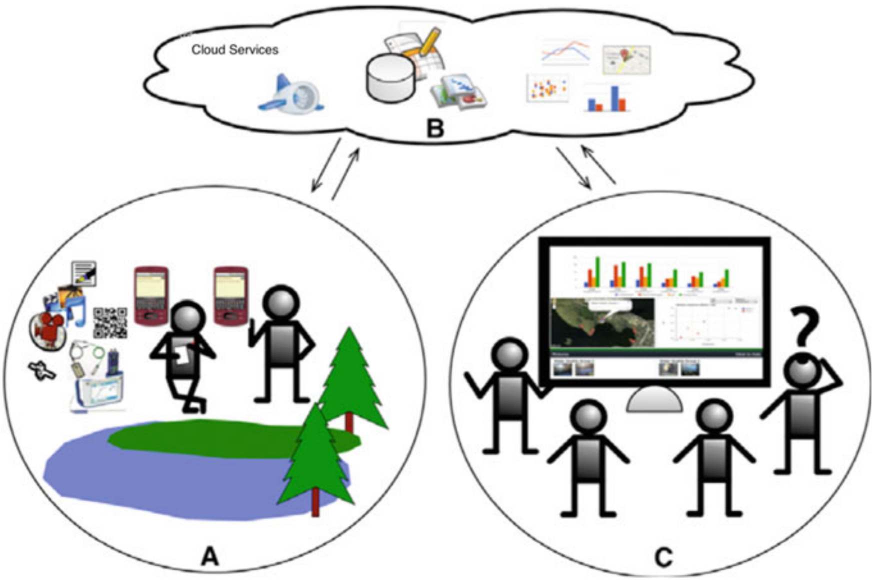

Fig. 4 Conceptualization of the different interactions in a LETS GO activity (Vogel et al., 2014)

manner that required design and development efforts to consider MSL dimensions (Wong & Looi, 2011; Wong et al., 2015).

This activity can be followed up by preparation for investigations and experiments to be conducted using different technologies (probes, data loggers, mobile applications for data collection in the classroom). Additionally, learners can conduct field experiments within the local environment and collect samples for laboratory analysis. Data collected using the mobile data collection tool included geo-tagged content and sensor data (usually pH, dissolved oxygen, temperature, conductivity, moisture, etc., depending on the type of activity). This learning activity usually ends with a discussion of the findings from the field and laboratory work, and an overall class discussion and reflection using the Web visualization tool, which tailors the different geo-tagged sensor data and digital content collected using the mobile data collection tool. In this case, we used XML and JSON to store and share the teacher's and students' interactions between mobile devices. A Moodle learning management system was used to support this activity.

3.3 Case 3: Interactive Videos

In this activity, we asked students attending computer science and programming courses at Bachelor's and Master's levels to track educational videos and convert them into interactive and rich media learning opportunities. This learning activity was designed for undergraduate students learning essential terms in the field of computer science. The design and development of this activity also required addressing various concerns reflected in MSLs (Wong & Looi, 2011; Wong et al., 2015).

The activity is technologically supported by the EDU.Tube authoring environment, which enables students to incorporate video clips found on YouTube with educational interactions. In addition, the activity includes other orchestrated interactions related to those of EDU.Tube that are supported by another environment called Collaborative e-Learning Structures (CeLS). This activity consists of four sequenced phases and starts by requiring students to look for videos with educational potential, which may assist with the teaching of concepts related to computer science and programming. Students are also required to author educational interactions and to incorporate these into scenes they have identified in videos, aiming to transform them into interactive and educational opportunities. In Fig. 5, we illustrate an educational interaction incorporated into a video, thus transforming it into an educational opportunity.

In the figure, we illustrate a student's interaction, occurring when the video reaches a predefined point in its timeline (see the left-hand side of the illustration). In this case, arrival at a predefined point triggers the appearance of an educational interaction, as illustrated on the right-hand side of the figure.

In the following phase, students are asked to assess seven interactive video clips, authored by their peers within the same study group. Students conduct their assessments using regular or mobile instances of EDU.Tube on their own devices of various types. In the next phase of the activity, students are required to select the three best

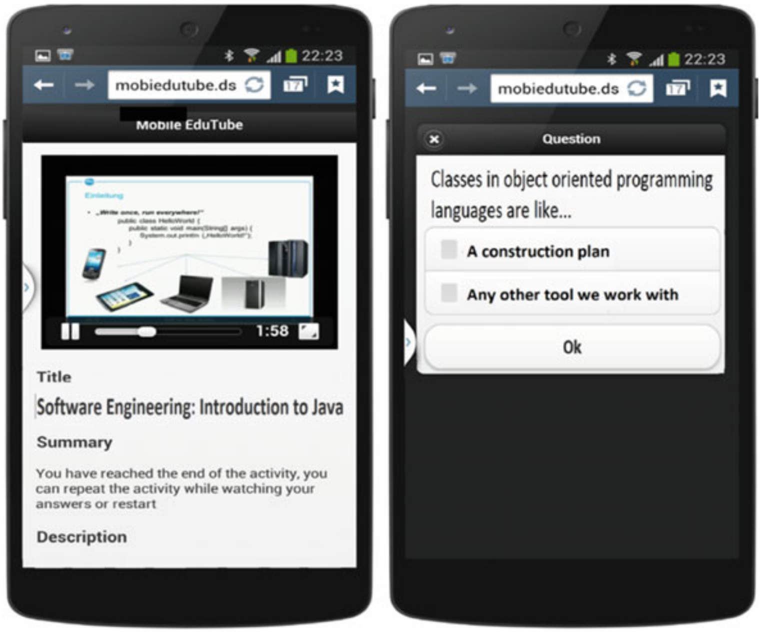

Fig. 5 Illustration of educational interaction involving topics in software engineering as experienced on a mobile device

videos authored by their peers and are required to support their selection with a text-based justification. The final phase of this activity takes place during a debriefing session in which teachers use CeLS and EDU.Tube to present selected (mostly voted on) videos to the students. Teachers also discuss the students' insights, as expressed by their fellow students during the peer assessments. Selected artefacts are used in the debriefing session as educational and attractive opportunities, recognized as pedagogical contributions by both the teachers and the students.

4 Mapping the Educational, Organizational and Technological Dimensions of the Described Cases

The design of CSL activities, as described in the cases mentioned above, includes various educational, administrative and technological requirements that need to be considered by researchers, teachers and developers during their deployment efforts. In particular, these considerations play a crucial role in the educational design of such activities, as well as in work focused on technological development that aims to alleviate administrative and pedagogical challenges.

As previously discussed, the educational, administrative and technological aspects of such activities are addressed through various MSL dimensions, as described in the list below (Wong & Looi, 2011; Wong et al., 2015):

- (MSL-1) Encompassing formal and informal learning
- (MSL-2) Encompassing personalized and social learning
- (MSL-3) Learning across time
- (MSL-4) Learning across locations
- (MSL-5) Ubiquitous access to learning resources
- (MSL-6) Encompassing physical and digital worlds
- (MSL-7) Combined use of multiple types of devices
- (MSL-8) Seamless switching between multiple learning tasks
- (MSL-9) Knowledge synthesis
- (MSL-10) Encompassing multiple pedagogical models

In the following paragraphs, we will target three of these dimensions that are most relevant to our research and deployment work. We focus on MSL-2 to address the social nature of the educational interactions, MSL-4 to reflect the nature of the educational process exercised across locations, and MSL-7 to examine the combined technological means required for interactions in the context of mobile learning. Table 1 illustrates various aspects of CSL and their application in terms of MSL dimensions.

In this table, we present the aim and goals for each case, including their educational, logistical and technological challenges. In addition, we show how these aims

Table 1 MSL dimensions reflected in CSL deployments

Dimensions mainly addressed	Case 1: Usability issues	Case 2: LETS GO	Case 3: Interactive videos
(MSL-2) Encompassing personalized and social learning	CeLS	Moodle	CeLS
(MSL-4) Learning across locations	Indoors and outdoors	Indoors and outdoors	Anywhere
(MSL-7) Combined use of multiple types of devices	MoCoLeS, CeLS Integrate CeLS and MoCoLeS to support the design and enactment of CSL activities to be performed outdoors using mobile devices, and indoors using stationary computers	Proprietary mobile client LETS GO, used with Moodle system Integration with external services to provide various services, including maps, visualizations, forms, spreadsheets and Flickr services	CeLS and mobile EDU.Tube Integration of two approaches to support the design and enactment of CSL activities enabling students to author and interact with educational video clips from anywhere, using stationary and mobile devices

and goals are achieved through technological implementations, including the use of Web and mobile technologies that are integrated and communicate with databases. The table illustrates various aspects that need to be considered in the deployment efforts for each of the CSL activities. These varied aspects represent opportunities and challenges that must be acknowledged or tackled during the design and deployment of these activities. In the next section, we propose an approach to iterative design that enables the gradual alleviation of the interrelated concerns that typically exist for such CSL activities.

5 The Proposed Approach to Designing CSL Activities

In this section, we propose a design process that offers an approach to addressing the various challenges that typically exist in CSL activities, including:

- Orchestrating educational tasks that reflect pedagogical approaches;
- Specifying educational tasks with social, temporal and location settings;
- Technological support for the actual interactions taking place throughout the phases of the designed activities;
- Providing an effective means for the evaluation of CSL activities.

As shown in Table 1, these opportunities and challenges align with MSL dimensions (focusing primarily on MSLs 2, 4 and 7). Specifically, the first and second points relate to the elicitation of requirements for educational tasks reflecting various educational aims. The second point is related to the organizational aspects that need to be set for these educational tasks; as stated in MSL-2, these reflect the social settings of educational processes. The next point addresses the ubiquitous nature of CSL activities, as reflected in MSL-4. Finally, we address the technological means required to support these activities (the nature of the devices mentioned in MSL-7). The last point addresses aspects related to the evaluation of such CSL activities. As mentioned in the introduction, these challenges in terms of educational design have been addressed by several different researchers, including Wong and Looi (2011) and Milrad et al. (2013). Kohen-Vacs (2016) proposes a design approach adapted from research efforts carried out by Ravenscroft, Schmidt, Cook, and Bradley (2012). These ideas are illustrated in Fig. 6.

In Fig. 6, we illustrate our proposal for a design process that spans three iterations. In the first iteration, we suggest considering and carrying out various design tasks, including:

- Prioritization of aspects reflected in the different MSL dimensions, concerning the goals and challenges of the activities. This prioritization aims to enable the design of activities for multiple purposes while conceptualizing their educational, organizational and technological aspects.
- An exploratory phase that examines the experiences and constraints related to different aspects of the CSL activity.

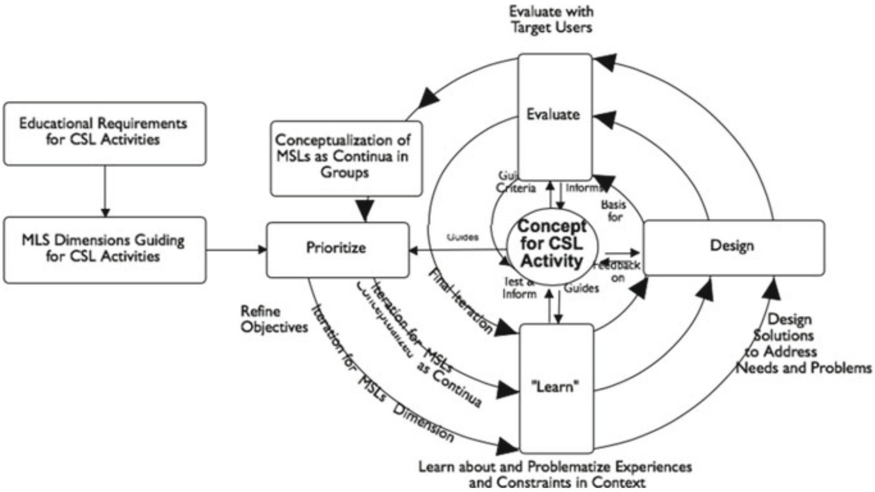

Fig. 6 Spiral iterations included in the mature design process. Adapted from Ravenscroft et al., 2012)

- A practical design process that aims to provide potential solutions linked to implementations of CSL activities.
- An evaluation phase that addresses the ongoing design process and focuses on how the diverse MSL dimensions were conceptualized in the previous design process.

These tasks are repeated in the next iteration, while conceptualizing MSLs in the same continua (Milrad et al., 2013). The last iteration includes a final session that aims to assess the challenges arising from previous iterations requiring additional adjustments. In the next phase, the final design is evaluated and proposed as a mature concept of a CSL activity, to be offered for adaptation and reuse in the future. In this section, we propose a process that offers researchers and teachers the opportunity to conceptualize and design CSL activities while taking into consideration their educational and administrative requirements. In addition, this design process offers an opportunity to identify the technological aspects that need to be developed and deployed in order to provide support for such activities. The spiral approach proposed by Kohen-Vacs (2016) was inspired by and accordingly shares characteristics with the interventions used in design-based research (Anderson & Shattuck, 2012; Brown, 1992; Collins, 1992). This approach also aims to provide an iterative process focusing on repeated interventions, testing and improvement, towards the best design of mature concepts, and thus better serving educational processes.

In the next section, we present our proposal for a software architecture that offers support for CSL activities, including the range of aspects reflected in MSL dimensions.

6 From Design to Technological Deployment of CSL Activities

In the previous sections, we illustrated various aspects that should be considered during the implementations of CSL activities, and discussed both the educational and administrative aspects related to these kinds of learning interactions. Furthermore, these administrative aspects could be examined as organizational challenges which need to be addressed in order to implement such activities. Over the past decade, numerous research efforts have dealt with some of these challenges, referring to them as orchestration challenges for collaborative learning activities (Håklev, Faucon, Hadzilacos, & Dillenbourg, 2017; Roschelle, Dimitriadis, & Hoppe, 2013). As mentioned above, CSL activities intensify these kinds of challenges in activities such as those presented in the previous section, including the collaborative aspects. Consequently, we find that these challenges could be supported by a set of interrelated services included in a service-oriented architecture.

In the previous subsection, we elaborated on the design of mature CSL activities, illustrating how the dimensions are conceptualized through an iterative design-based process. Within this process, we suggest examining the various aspects of CSL activities as reflected by the MSL dimensions. We also examine how these aspects combine towards the establishment of more mature concepts for CSL activities. Such an architectural approach is well-known in the context of service orchestration and can potentially be implemented for the orchestration of educational interactions (Mayer, Schroeder, & Koch, 2008). For example, in the proposed design process, we consider the requirements for supporting educational interactions in terms of both mobile and more traditional learning. This variety of interactions may require the use of services supporting different types of interactions, e.g. synchronous or asynchronous interactions.

In Fig. 7, we illustrate our proposal for a general architecture to support the implementation of CSL activities. In this illustration, we do not intend to present an architecture for an abstract concept. Instead, this presentation aims to suggest an architecture which is close to implementation.

The illustrated architecture is based on a service-oriented approach and includes the integration of components that are intended to offer different functionalities, resulting from the outcomes of the design process. This representation of the architecture is designed to be as close as possible to an implementation, while offering an applicable approach aligned to the practice of CSL activities. This architectural approach allows implementers to choose from a set of services, but does not require the deployment of all of them. In addition, the nature of this architecture allows the possibility of implementing new cases while easily introducing any new services required. These new services could serve and be reused in additional cases supported by this architecture.

For interactions, such as those required for the LETS GO project or the activity focusing on usability issues, an XForm component was adopted and integrated, in order to support students' interactions across locations. In addition, teachers and stu-

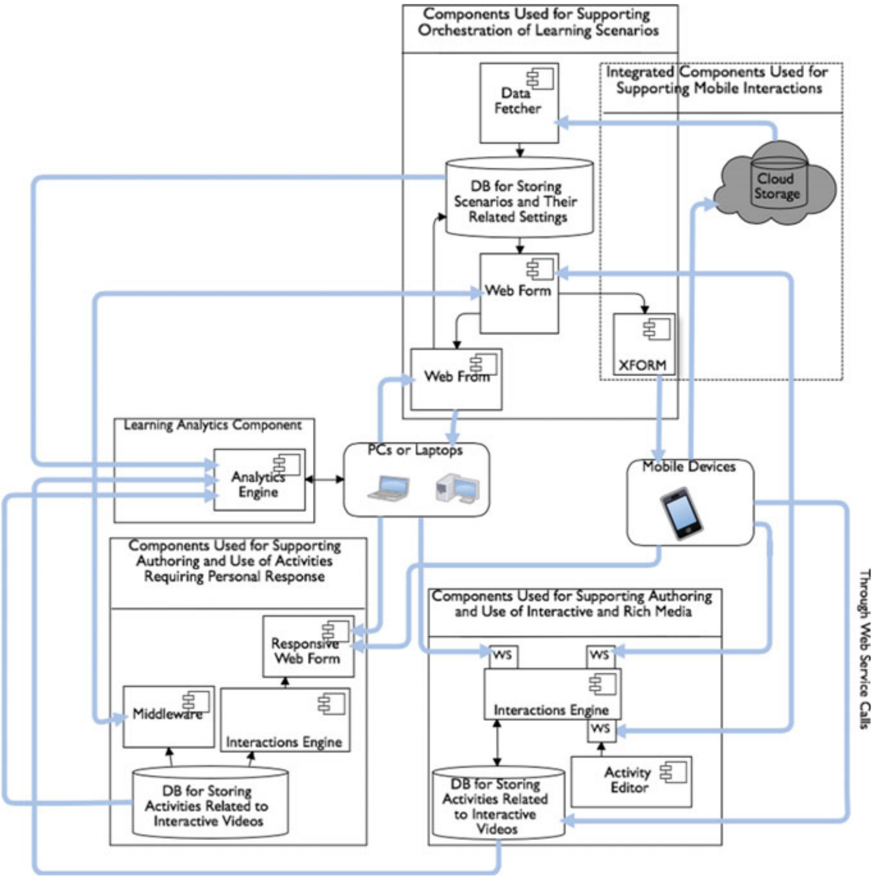

Fig. 7 Overview of the proposed architecture

dents can interact in various modes in these activities, while using services supporting personal responses across contexts. Activities consisting of rich and interactive media, such as that dealing with interactive videos, may be supported by components enabling teachers and students to experience such content on mobile or personal computers. As illustrated in Fig. 7, we consider the deployment of micro-services, including one responsible for handling interactions with rich media. This micro-service uses its own database to store its own interactions; however, it also uses an additional database that is responsible for handling the additional data needed to use this service throughout orchestrated activities. As shown in the figure, the micro-services deployed in this architecture are interconnected in a way that allows their use during the orchestration of a certain activity. In addition, these services could be reused in various other activities that use different settings for orchestrations requiring the same kind of technological support. It should be mentioned that our approach is aligned with other research efforts involving activities based on an architecture providing various options for the contextualization of micro-services offering rich options and flexibility, in terms of support for various types of educational content and various ways to mediate this across technologies (Sharples, 2015; Sotsenko, Zbick, Jansen, & Milrad, 2016). Finally, the proposed architecture includes an analytical service that is interconnected with the orchestration components, including the databases corresponding to the various reusable micro-services and the database storing the CSL scenarios. This integration of the analytical service aims to allow future analysis, based on the interactions offered and supported by different types of micro-services for users who are organized in various social settings. Eventually, this feature will allow a better understanding of the educational processes practiced in CSLs and will enable possible supportive interventions (Prieto, Sharma, Dillenbourg, & Jesús, 2016).

We suggest that this type of architectural approach can offer technological support for the implementation of a mature concept for a CSL activity. Technological support for the proposed design approach relies on integration of the technological components required to support the various aspects of CSL activities. In addition, the incorporation of these components into the architecture was achieved while emphasizing the generation, sharing and reuse of content, based on the aspects typically required by teachers when designing educational activities for real settings. It should be mentioned that this architecture provides rich possibilities for reuse at two levels: the educational content level (learning materials) and the technological level represented by the implemented services. The realization of this sharing and reuse of generated content is addressed in Fig. 3 by including middleware and Web services. In addition, this architecture provides rich possibilities for reusing the components for newly introduced services, as discussed above.

7 Summary and Conclusions

In this chapter, we present an ongoing effort to propose new approaches for designing, developing and deploying CSL activities. This effort is based on investigations carried out over the past decade. Here, we report a sample of these efforts applied to three activities, designed with a focus on collaborative and seamless learning experiences. In particular, we describe activities enabling teachers and students to benefit from collaborative and seamless learning experiences within various domains, including usability issues, environmental studies and computer science.

This study includes one learning activity connected to the LETS GO project, which involves environmental studies; another activity that allows students to learn about usability issues in authentic settings; and an activity focusing on the authoring and exploitation of new educational opportunities through interactive videos. We also describe the interactions and technologies used to support various use case scenarios, including indoor and outdoor interactions involving data collected from real settings and later reused as new educational opportunities. In addition, we allow the teacher and students to interact with rich media from anywhere and at any time. We then summarize our discovery and analysis efforts focused on aspects of CSL activities, while reflecting on them in terms of the educational, logistical and technological requirements inherent in the MSL dimensions. In this sense, we argue that the MSL dimensions can be exploited as a convenient means of analysing and then designing and deploying such activities. Our proposal recognizes the different MSLs and considers their use throughout the design, development and deployment of CSL activities. We suggest this as a process that can potentially provide researchers, designers or teachers with new opportunities to evaluate their educational efforts in a comprehensive way. In the subsequent steps of the design, we propose an iterative process consisting of several steps, including prioritization of the aspects related to CSL activities, which is followed by another exploratory phase addressing the experiences with and constraints on such efforts. In the subsequent steps, the actual design is produced, and this is followed by an additional evaluation phase that may lead to additional cycles of refinement. We believe that our proposal can offer a convenient and robust approach for researchers, teachers and other practitioners seeking ways to achieve, implement and reuse mature designs for CSL activities. Furthermore, we believe that there is a strong relationship between mature designs for CSL activities and their novel implementations. We argue that the exercise of best practice during the design process opens the way to optimizing the practical potentials of such activities while being technologically implemented.

We also find that this approach aligns with our aims, as presented in our research question regarding how best to design systems and tools to support students during the enactment of collaborative seamless learning. We propose an approach that allows an analysis of the requirements related to the actors conducting and participating in such activities. We also consider the educational, administrative and technological requirements relevant to the enactment of these types of educational enactments. Furthermore, we propose the utilization of MSL dimensions to facilitate identification of the various types of affordances and challenges that need to be tackled in the deployment of these activities, and propose the use of these dimensions in a comprehensive way to iteratively design and develop such activities. These efforts encompass both the educational and technological aspects required to support them across contexts and settings. In particular, our approach considers the various stakeholders typically involved in such deployment efforts, and we offer a deployment framework involving the various specialists with the corresponding tools enabling them to conveniently exercise their professional practices throughout the design and development of CSL activities. Furthermore, the exploration and development aspects of our approach acknowledge and encompass the varied expertise of the different stakeholders, addressing interrelated framework for deployment. These efforts were consolidated into a deployed activity consisting of micro-services that offer the capability to address educational requirements in terms of interactive content and the corresponding technology required to support it. We also offer these efforts for reuse and implementation in other educational activities, possibly orchestrated across other settings.

In summary, we suggest the implementation of a novel architecture aimed at CSL activities reflecting the proposed design approach. This architecture is service-oriented and is flexible enough to enable expansion and the introduction of new services to support new functionalities. These services may be required by new activities or could be reused in the case of new activities requiring the same services as those previously implemented. We demonstrate that the suggested architecture enables the introduction, exploitation and reuse of its components containing various services. In terms of the actual educational data supported by such services, we find that this interrelated set of services supports the introduction, interaction and reuse of existing educational content. In future work, we will further refine our approach to CSL activities, while considering those with new educational and innovative functional requirements. In addition, we will maintain and keep up to date our architectural approach so that it better supports innovations emerging from future CSL activities.

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Chapter 6
Crossing Over Settings, Practices and Experiences: Connecting Learning in Museums and Classrooms

Koula Charitonos

1 Introduction

It is hard to move museum experiences back into the classroom. Despite evidence showing that learning is positively influenced by making connections of the classroom experience to museum experience (cited in Brody, Bangert, & Dilon, 2009) or that learning often becomes more prominent when prolonged with subsequent activities (Anderson, Lucas, Ginns, & Dierking, 2000; Falk, Scott, Dierking, Rennie, & Cohen Jones, 2004), in reality school trips to museums are often disconnected from other learning experiences students have at the school or beyond for a number of reasons (e.g. curriculum pressure). This chapter addresses one specific challenge, namely the need to understand and promote learning across school and out-of-school contexts. Addressing this challenge is important for researchers and practitioners who are interested in connecting classroom learning and out-of-classroom learning spaces in order to create rich and holistic learning experiences for the students. This approach to a 'learning ecosystem' is consistent with what Pea (2009) argues: 'we need to treat the activities and life experiences of the learners throughout the day as our units of learning design, description and explanation' (cited in Chen, Seow, Hyo-Jeong, Toh, & Looi, 2010, p. 46).

Indeed, researchers have for the last decades developed an interest in exploring how to design, enable, support and research learning and collaboration across different locations and contexts to generate robust activities and meaningful learning experiences (e.g. see Wong, Milrad, & Specht, 2015). This increased attention in recent educational research and practice is becoming particularly prominent due to the proliferation of mobile and ubiquitous technologies and is well aligned to a phase in technology-enhanced learning (TEL) characterised by *seamless learning spaces* and marked by continuity of the learning experience across different scenarios or

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contexts emerging from the availability of one device or more per student (Chan et al., 2006). Similar to Toh, So, Seow, Chen, and Looi (2013), the term 'seamless learning' is used in this chapter to refer to the integrated and synergistic effects of learning in both formal and informal settings, which is distributed across different learning processes (emergent or planned) as well as across different spaces (in or out of class) (p. 301). It is noted that the term *seamless learning* is a term typically associated with positive connotations and implies a continuous flow of the learning experience, where students can easily and quickly switch from one scenario to another using the personal device as a mediator. That said the mere availability of devices or advanced mobile connectivity is not sufficient to address the complexities embedded in a learning ecosystem, and indeed, the effort of designing effective technology support along with appropriate pedagogy and consideration of social practices is more complex than imagined (Stahl, 2002)—also highlighted by a number of contributions in this volume.

This chapter moves beyond simplistic questions of whether or not mobile technologies have a place in the classroom or museums, and unlike previous mobile learning research—often focused on the development and deployment of technological systems in either formal or informal settings (e.g. see Chen & Huang, 2012; Sharples et al., 2014)—the chapter considers timely, practical and nuanced questions that concern the TEL field, namely:

(i) How does technology shape and/or change pedagogical approaches to mediate crossovers between settings, practices and experiences?
(ii) How can we divert attention from technologies to focus on creating pedagogical strategies to exploit the use of seamless environments for teaching and learning?

To address these questions, the chapter draws on a well-designed and implemented study that took place in the context of a secondary school in the UK and involved a visit to the Museum of London (MoL) in the UK. Students, aged 13–14 s, were equipped with mobile phones with Internet connectivity and were asked to use a microblogging technology (i.e. Twitter) in the classroom and the museum. This study did not rely on a design-in support system, namely a technological system developed and deployed to serve the specific research aims of the study. Instead, a widely available social media platform, i.e. Twitter, was employed and embedded in a series of blended lessons in a classroom and beyond, to examine how features and uses of a Web 2.0 technology can provide a mechanism to connect formal and informal learning experiences (see Sect. 3.2). The emphasis of the study, hence of this chapter as well, is not on technological connectivity but on the processes that may enable learning to occur across contexts and particularly on considerations and enactment of pedagogic strategies. This is in line with other researchers in the field (Nicholas & Ng, 2015; Wong, 2012; Wong & Looi, 2011) argued for, namely that we need to place attention not only on to technological resources but also to pedagogical means to support knowledge synthesis and skills development.

An outline of this chapter is as follows: first the theoretical framework on *mobile pedagogy* (Kukulska-Hulme, Norris, & Donohue, 2015) is outlined, followed by a discussion on how the affordances of mobile technologies can support *crossover* *learning experiences* (Sharples, Adams, Alozie, Ferguson, FitzGerald, Gaved, … Yarnall 2015). This is followed by a review of the literature on mobile learning in museums. At the core of the design of the study that is presented in Sect. 3 is a *mobilised visit* to a museum, after the term 'mobilised lesson' (Norris & Soloway, 2008; cited in Looi et al., 2009, p. 1121). It is used here to describe a visit that is designed to resemble a 'traditional' school visit to a museum (e.g. use of worksheets, learning objectives), but then is transformed to make use of the mobile and online technology's affordances in ways that take advantage of the strengths of both the museum and the classroom learning environment. Three examples drawing on empirical evidence are provided in Sect. 4 to illustrate the concept and show how design decisions by the researcher and the teacher led to a mobilised visit that was designed through the museum and the classroom, weaving together activities, tools, practices, interactional moments and pedagogic considerations in an attempt to make use of technological affordances to address formal learning objectives. These examples, framed by the concept of *mobile pedagogy* (Kukulska-Hulme et al., 2015), highlight pedagogical strategies that were enacted in the classroom and beyond. The work reported here is intended to explore the potential ways to put the concept of seamless learning in practice, and as such, it concludes with a discussion around how to enact mobile pedagogic practices to integrate technology in ways that learners may benefit from the crossover between formal and informal learning experiences.

2 Theoretical Background

2.1 Mobile Pedagogy for Crossing Over Museum and Classroom Learning Experiences

The chapter draws on the concept of mobile pedagogy (Kukulska-Hulme et al., 2015), which offers a potential lens through which some practical issues regarding a mobilised visit can be addressed. Despite its original focus on English language teaching, it is seen as providing a pedagogical perspective through which to research and promote learning as a holistic experience that stretches beyond the classroom. According to Kukulska-Hulme et al. (2015), mobile pedagogy places particular attention on the teacher as the person who enacts the pedagogy by considering it in relationship with other parameters in the context of an activity. To further crystallise what mobile pedagogy entails, it is useful to note how the authors outline the four key characteristics of 'mobile pedagogy' as being related to the teacher wisdom (e.g. classroom management techniques), device features (e.g. camera), learner mobilities (e.g. places and times when people can learn) and subject dynamics (e.g. practice language). An approach to mobile pedagogy for crossover learning experiences is based on the view that teachers and learners are active participants in learning while designing and moving in, and across, different physical and social spaces mediated by technology. This implies that learners take responsibility for their own learning and that teachers (and museum educators in the case of a mobilised visit) play their part in enabling this. As such, this chapter considers the role of the technology on supporting both teacher and learners to orchestrate the process of connection and continuity of learning and marks an attempt to shift the site of discussion from the development of technological systems towards a richer understanding of the complex relations between learners, technologies and spaces involved. This pedagogical framework is seen as supporting teachers to consider technology-enabled crossover learning events. The three examples that are provided below draw on this framework and highlight pedagogical strategies that were implemented in the course of this study to exploit the use of seamless environments for teaching and learning.

2.2 How Mobile Technologies May Support Crossover Learning Experiences?

The chapter is built on the premise that making connections and facilitating transitions between informal and formal, home and school, physical and digital are not only desirable but are also set to dominate advancements in education practice and research. It therefore focuses on the concept of crossover learning (Sharples et al., 2015), which is linked to seamless learning, but as the term implies, places greater emphasis on connectivity and refers to a comprehensive understanding of learning that bridges formal and informal learning:

> These connections work in both directions. Learning in schools and colleges can be enriched by experiences from everyday life; informal learning can be deepened by adding questions and knowledge from the classroom. These connected experiences spark further interest and motivation to learn (Sharples et al., 2015, p. 3).

Building on this, crossover learning can be seen as an attempt to frame new understandings of learning that are made possible in part by the affordances of mobile and Web technologies. It allows to reconsider traditional modes of pedagogy in order to create learning ecologies that are better attuned to our times and may also benefit from crossovers between traditional institutional, spatial and temporal boundaries of education. Crossover learning is seen as helping learners to connect experiences gained throughout the learning ecosystem (Sharples et al., 2015), but it arguably puts teachers and classroom learning on the spotlight as it highlights the need to revisit questions, such as: what do we mean by formal/informal learning, what skills and competencies need to be developed to allow opportunities for unguided activities outside the classroom, what pedagogic practices do teachers need to engage with in order for crossover learning to take place, and essentially, what we need to be doing in the classroom when the distinction of time and space no longer matters?

The study presented in this chapter provides an example of crossover from formal to informal learning by examining a museum visit. As Sect. 3 shows, the visit followed certain degree of structure, namely formal aims were set, evidence gathering was linked to subject-based questions that guided the actions of students, while resources traditionally associated with museum visits were developed (e.g. worksheets). At the same time, the design of the visit drew on characteristics of informal learning, i.e. ‘all forms of intentional or tacit learning in which we engage either individually or collectively without direct reliance on a teacher or externally organised curriculum’ (Livingstone, 2006, p. 204). In this context, the concept of crossover learning encourages us to rethink the museum visit as primarily a connected experience, initiated in the classroom and continued at the museum and through follow-up classroom activity and to further consider the supporting role of the technology to orchestrate the process of connection and continuity of learning.

Mobile technologies offer numerous possibilities to exploit the strengths of the museum and the classroom environment and provide the learners with authentic and engaging opportunities for learning. Inquiry-based learning has been increasingly suggested as an effective educational approach in which learners can develop knowledge through exploration and investigation about the phenomena that they observe in the physical world, and they also get an understanding of how to perform the steps of scientific inquiry (Scanlon, Anastopoulou, Kerawalla, & Mulholland, 2011). Mobile technology is appropriate support for this approach, and a number of mobile learning projects have been discussed in the literature where, for example, mobile devices support inquiry learning that is extended across settings by providing access to content, apps and resources (e.g. Jones, Scanlon, & Clough, 2013; Rogers, Connelly, Hazlewood, & Tedesco, 2010); using features of the devices (e.g. cameras, sensors) to collect and input information while being in the field (e.g. images, sounds, notes) (Liljeström, Enkenberg, & Pöllänen, 2012; Sharples et al., 2014); interacting socially to achieve certain learning goals (Charitonos, Blake, Scanlon, & Jones, 2012). A recent review of studies in mobile inquiry-based learning (Suárez, Specht, Prinsen, Kalz, & Ternier, 2018) identified five types of mobile activities, namely (i) direct instruction, (ii) access to content, (iii) data collection, (iv) enable communication and (v) contextual support. The starting point of their review was whether the learner-centric approaches supported with mobile technology, such as inquiry learning, enable learners to take responsibility on their learning process (learners' agency). A similar question was raised by Wong et al. (2015) a few years earlier and was concerned with the extent that the properties afforded by mobile technology can really lead to effective seamless learning processes.

Indeed, while many studies report the importance and effectiveness of engaging students in mobile technology-supported in-field learning (Hwang & Wu, 2014), research shows the management of the technology itself can be challenging for learners and teachers (Sharples et al., 2014), while learning in such environments might become too complex and learning achievements could be disappointing (Chu, Hwang, & Tsai, 2010). A recent meta-analysis by Sung, Chang, and Liu (2016) focused on the shortcomings linked to the duration of interventions, the methods of measurement of higher-level skills, and also on the weak orchestrations of mobile activities in generic learning activities. Their analysis shows that features of mobile technology (e.g. real-time access to information, context sensitivity, instant communication, feedback) are not sufficient conditions for positive learning effects and suggest the match of these features to the resolution of specific pedagogic challenges. Aligned is a finding by Wong and Looi (2011), who suggest that further studies are required to encompass multiple pedagogical or learning activity models, to support seamless switching between multiple learning tasks as well as to enhance seamless use of multiple device types.

Drawing on this, the chapter provides an example of a crossover experience from a classroom to a museum to illustrate how pedagogic strategies were employed to support learners in their transitions between formal and informal context.

2.3 How Mobile Devices Are Used Within and Beyond the Museum?

The museum sector has been at the forefront of research in digital and mobile learning, reflecting a growing commitment within the sector to deploy technologies as means to augment the museum space or go beyond the physical limitations of the material artefacts and space itself. A number of applications have been developed (e.g. Hsu & Liao, 2011; Vavoula, Sharples, Rudman, Meek, & Lonsdale, 2009), whilst increasingly, visitors' own smartphones are employed to capture impressions and reflections and have become an integrated part of browsing and social practices in gallery and sharing online (Hillman, Weilenmann, Jungselius, & Leino Lindell 2014). What underpins most of these developments is a vision to enrich the visitor participation and enhance their engagement with, as well as maintain their appreciation of, the authentic artefacts. This is in response to concerns expressed about the use of digital and mobile technologies in museums, including diverting attention of the visitors, isolating and inhibiting social interaction (Hsi, 2003) or diminishing the perceived value of the original artefact (Petrelli, Ciolfi, van Dijk, Hornecker, Not, & Schmidt, 2013).

Over the last decade, an increasing number of researchers have focused on studying technology-enhanced museum learning, with some researchers in particular examining use of technology by young people in school visits (e.g. see Hillman et al., 2014; Vavoula et al., 2009). For example, the Gidder project (Pierroux, Krange, & Sem, 2011) explored online communication across settings, and particularly the potential of user-generated content, to motivate students in the museum and support reflection back in the classroom. Similarly, MyArtSpace (Vavoula et al., 2009) provided a service on mobile phones to support children's inquiries during their museum visits. Findings pointed to the use of the MyArtSpace service as being effective in enabling students to gather information in a museum, more motivating for students compared to traditional worksheets, and helps to 'bridge' different learning settings by making information captured, generated or accessed in one site available in another. However, the researchers also suggested that students need more structure and guidance to help them make sense of the data they collected, especially when they are back in the classroom. Hillman et al. (2014) took a different approach as they relied on students' own technologies and explored features on smartphones (i.e. cameras) to investigate the students' engagement with exhibits. More specifically, the authors examined how students structure their visits with walking paths through the museum exhibitions and the multimedia products they create as a form of narratives that students produce to complete the tasks during the visit by using the tools at hand and incorporating different parts of the exhibits.

These three projects highlight the notion of seamless learning by making use of technological affordances to support learning in the museum and beyond. They were designed to address the issue that school museum trips are disconnected from classroom learning. Drawing insights from the literature, it is also useful to consider that these projects mark a shift in the interest to learner-created content in authentic environments such as museums and classrooms. The study that is presented in this chapter sought to bridge the gap between school-specific tools and everyday tools; hence, it employs Twitter that could be used without any constraints across multiple physical contexts. Further information about the research design follows in the next section.

3 Research Context

3.1 Aims and Objectives

The research design sought to seamlessly integrate the learning experiences across various dimensions including formal and informal learning contexts, individual and social learning, and physical and virtual world, as indicated by Wong and Looi (2011). As a result, the study was designed based on a pre- and post-visit approach focusing on a specific area of Key Stage 3 (KS3) History curriculum. The design sought to integrate a Year 9's work around 'Equality and Beliefs' into a long trajectory of whole-class activities with specific objectives that span over several sessions across the museum and the classroom. The project aimed to examine how students' development of understanding on disciplinary knowledge, i.e. civil rights, develops over time and is materially realised over several modes (visual, writing and oral) and media (e.g. online platforms). The main goals of the visit were the students (i) to investigate, individually and as part of a team, specific inquiries related to the visit's theme and KS3 curriculum (e.g. how do people change the societies they live in?), (ii) to select evidence from museum artefacts and provide interpretations for them, with a purpose to evaluate and critically reflect on their inquiries and reach reasoned conclusions and (iii) to communicate their knowledge and understanding to an audience, either online or face to face.

3.2 Tools

Ogata and Yano (2004) identified six requirements that technologies should meet if they are to be considered compatible with ubiquitous learning, namely permanency, accessibility, immediacy, interactivity, situating of instructional activities and adaptability. Twitter was the main tool selected in this study as it was seen as enabling these characteristics. It is a tool that is embedded in one's daily life and across contexts and can be accessed from anywhere. It has both synchronous and asynchronous attributes, and it also introduces the possibility of enhancing the dialog 'diachronically', i.e. endured in time (Elavsky et al., 2011, p. 6). Research has shown that it can be used as an educational tool as it provides an opportunity for interactions and feedback (Elavksy, Mislan, & Elavsky, 2011, Junco, Heiberger, & Loken, 2011). Hence, Twitter would allow the researcher to collect participants' reactions to what they experience at the museum. Twitter has a simple interface, so teenagers (13–14 s) could engage with its user-friendly features without any complexities. Another advantage of selecting Twitter was that it could be used even in the case of a 3G network not being available in the museum setting. This was feasible because in the UK users could update their status by using a text messaging service available in the mobile phones, i.e. Short Message Service (SMS). Finally, due to its short text format (140 characters until Nov 2017), there was an assumption that the use of Twitter on mobile phones would be straightforward and would not create the 'heads-down' effect (Hsi, 2003) that is reported in the literature when technology is used in a museum space.

Another online tool (i.e. Vuvox)[1] was used in the classroom following the visit for creating multimedia presentations, i.e. collages. Being an online tool meant that it could provide access anytime, anywhere. It allowed the creation of scrolling visual presentations with hot spots, i.e. video, music, pictures, text, and enabled uploading content within the museum itself.

3.3 Participants

The data was collected from a Year 9 History class (13–14 s) in a secondary school in the UK. The participants of the study were twenty-six students ($N = 26$).

3.4 School and Museum Activities

A number of lessons took place in the school before and after the visit (see Fig. 1), where face-to-face lessons (e.g. 'traditional' lesson on civil rights) were combined with technology-enabled activities (e.g. communication with the museum curator), either in the classroom or the school's ICT suite. Examples of how a lesson incorporated Twitter are provided below (Example A and C). The post-visit lessons involved students in groups creating an online presentation (i.e. collage) that would

[1] Vuvox: http://vuvox.com (discontinued as of September 2013).

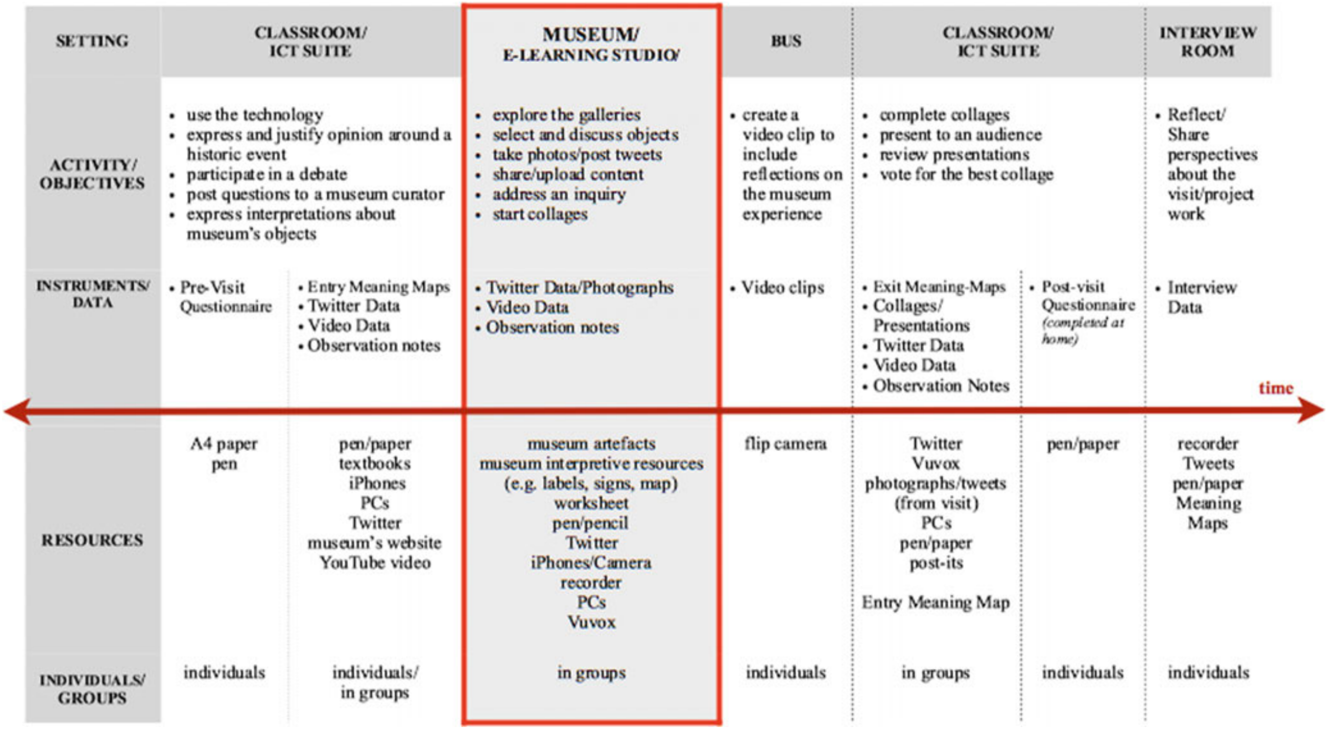

Fig. 1 Diagrammatic overview of the research design

be presented to their classmates (Example C). These presentations could point to identifying which of the many possible ideas and themes encountered in the visit become appropriated by the students and how the microblogging and the content created in the visit were helping the students to form these connections.

The museum visit was designed around the theme ‘Get Up, Stand Up: Fight for your Rights’, which is related to the KS3 Scheme of Work ‘Equality and Beliefs’. Museum of London[2] was selected as the site of the study because the Galleries of Modern London provide appropriate links to this Scheme of Work. A worksheet was designed through consultation with museum curators and the teacher to structure engagement in the museum (see Example B). In the visit, students were split into seven groups (of threes or fours). Groups of threes had one iPhone, while groups of fours were equipped with two iPhones, based on research suggesting that an optimal number of mobile devices per group of four to five students is two (Rogers et al., 2010). Each group was instructed to carry out some activities and collect some evidence with the use of iPhones and Twitter (i.e. notes, pictures and posts) in order to address an inquiry (in total, four different inquiries) and eventually, post-visit, create a presentation. The teacher and teacher assistants were present across the three galleries, and their role was restricted in observing and assisting with health and safety issues. Overall, the average time each group spent in each gallery was 20–25 min (approximately 75 min in total).

Table 1 provides an overview of the activities and features of pedagogy and how these were enacted in the study.

3.5 *Methods and Data Collected*

The study draws on a qualitative research framework and is informed by sociocultural perspectives of learning with a focus on mediating artefacts in the development of understanding in situated learning activities (Vygotsky, 1986). It selects the case study method to investigate how to understand the dynamic processes of learning situated across space and time, and how meanings are made and appropriated as they are mediated through social interaction and other tools across these settings.

Analytic attention was placed to students’ talk (face to face and online) in conjunction with encounters with artefacts and use of the microblogging technology. Therefore, the approach in the analysis of this data was to explore how meanings made were resourced in the talk among peers (see, e.g. Mercer, 2004) and in the use of other tools and artefacts (e.g. online posts, presentations). Hence, alongside talk, other mediational tools were considered in the analysis, as suggested by Mercer, Littleton, and Wegerif (2009). It is noted that the purpose was to offer a detailed, contextualised view of how topic understanding could be resourced through the students’ approaches to activities, objects and tools used. Furthermore, the analysis looked for signs which show ‘connection building’ (Littleton & Kerawalla, 2012), with a focus on examining whether artefacts/objects and tools encountered or used

[2]Museum of London: http://www.museumoflondon.org.uk/london-wall/.

Table 1 Features of mobile pedagogy and how they were enacted in the study

	Activity	Setting	Group formation	Pedagogy	How mobile pedagogy was enacted in the classroom?
Pre-visit	Communication with a curator	ICT suite—online	Individuals/in pairs	Live Learning/Real-time participation Communication with an expert Task-based Peer-to-peer interactions Learner autonomy Learners' interests	Students were engaged in synchronous participation online Students were asked to post questions/comments to a museum curator following exploration of the museum's website
	'Equality and Beliefs'	Classroom	Individuals/in groups	Face-to-face instruction In-classroom consolidation Interpretation of artefacts	Teacher facilitated a face-to-face discussion on this concept Students were asked to observe museum postcards (depicting artefacts) and provide interpretations Students were encouraged to discuss and express their views in their groups and whole class
Visit	Museum visit	Museum—online	In groups	Blend of physical and tech-mediated interactions Learner autonomy Inquiry Learning Collaborative learning Peer-to-peer interactions Observe and interpret objects Addressing an audience Different temporalities and spatial arrangements Supporting multiple learning paths Learners' interests Reflection	Students were engaged in face to face and synchronous participation online Students used worksheets and were asked to explore the museum, to record, discuss and document their views Students were asked to use smartphones and post multimodal texts online for each other to read and comment on Students started in different galleries and explored targeted objects and objects based on their inquiries and preferences
Post-visit	Presentations	Classroom/ICT suite—online	In groups	In-classroom consolidation Providing space and time for reflection Blend of physical and tech-mediated interactions Active learning Creation of artefacts Pedagogy of skills development, i.e. review Collaborative learning Peer-to-peer interactions	Teacher facilitated a face-to-face discussion on their experience of the visit and criteria for peer review activity Students were asked to review data collected in the museum, prepare and share a multimodal online presentation Students were asked to use smartphones and post their reviews online for each other to read and comment on

during the museum activities inform students' presentations and posts online and assist them in crossing over settings.

As shown in Fig. 1, the main empirical materials collected were interview data, video data and observation data, content created by students (e.g. tweets, collages, photographs), as well as pre- and post-visit Personal Meaning Maps and questionnaires. The evidence provided in this chapter is mainly drawn from three data sets: interviews, tweets and students' presentations.

All interviews took place immediately after the project was completed, and in total, eleven students were interviewed. The interviews with students were structured around four areas: (i) the visit experience; (ii) the classroom sessions, including the session with the museum curator; (iii) the use of the technology; and (iv) the students' Personal Meaning Maps. The interview with the teacher was structured around two main areas: (i) self-related questions and (ii) students/class-related questions. The focus was on the teacher's perspective on the project work, students' participation and learning and the use of technology. All the interviews were recorded and transcribed. Thematic analysis (Braun & Clark, 2006) was performed as a way to provide a rich and detailed yet complex account of data.

Regarding the data collected on Twitter, a descriptive numerical analysis of the tweets was initially provided. This was based on a few categories suggested by Elavksy et al. (2011); hence, the tweets posted during the classroom lessons and the museum were classified into nine broad categories, based on features of the tweet and its content, e.g. type of the tweet, task, hashtag, hyperlink to photographs. This was followed by a representation of the online discourse, drawing on an approach suggested by De Liddo, Buckinghamshire, Quinto, Bachler, and Cannavacciuolo (2011) to structure and represent the discourse as a semantic network of posts. According to the researchers, each post is coded according to its function in the conversation and is connected to a specific post or participant, according to the function of the post and its place in the conversation. As it is shown in Example A, the representations created had a focus on mapping the tweets as a network of posts and presenting the connections among the students. For this process, Compendium[3] was used which is a software tool for mapping information, ideas and arguments. The last step in the analysis of the tweets was the analysis of the content to identify the precise role of the tweets in the wider online discourse. All the tweets were coded according to eleven characteristics that emerged from the data (e.g. reflective, affective, illustrative), drawing on categories suggested in the literature (e.g. Silverman, 1999) (see Charitonos et al., 2012 for the characteristics).

The analysis of the students' presentations focused on how students resourced their multimedia presentation and whether there is evidence to show 'connection building', namely the meanings made across the settings and the role of the technologies in mediating this. To carry out the analysis, a multimodal transcript for each presentation was created, consisting of the original frames/slides, the text included in each of the frames/slides (i.e. Textual Mode) and the verbal presentation given by the students—if available (i.e. Oral Mode). This transcript also identifies resources

[3]Compendium: http://compendium.open.ac.uk/.

(i.e. tweets, photographs, verbal interactions, notes) that students drew on to create their presentation (see Example C).

The three examples that are described in the next section provide empirical material and show how pedagogic considerations have been included in the design of the learning activities pre-, during and post-visit, taking into account the technological affordances and social features of the learning activities, as well as established practices of organising a visit to a museum.

4 Enabling Mobile Pedagogy for Learning Across Contexts

4.1 Pedagogy #1: Live Communication with a Museum Curator (Pre-visit)

The first example of a mobilised visit focuses on a pre-visit lesson, which involved synchronous communication on Twitter between the students and the curator of social media at the Museum of London (MoL). A Twitter account (@MoLtrial) was created for the purpose of this lesson and was managed by the curator (i.e. protected tweets), while the researcher was handling the account @MuseLearn. The hashtag suggested was #MoLtrial. This lesson also involved screening of a YouTube video about Galleries of Modern London at the MoL (in MoL's official YouTube channel) and exploring the museum's website. Students were prompted by the teacher to express expectations from the visit and to post questions/comments to the curator. The duration of the lesson was fifty minutes, and the communication with the curator lasted twenty minutes; part of this lesson took place in the classroom and part at the school's Web-enabled ICT suite, where students were working individually or in pairs (see Table 2).

Data collected for this activity comprises face to face and technology-mediated interactions (i.e. tweets), interview data and observation notes. Table 2 shows the classification of the tweets into broad categories that were identified in an open coding of the data (see Sect. 3.4).

Twelve tweets were posted by the curator ($n = 12$) and twenty-three tweets ($n = 23$) by the participants (excluding noise). All the tweets are represented in Fig. 2 and are clustered around the users (or pairs) who posted them. The three tweets with the photograph icon are tweets with links to images of objects. Figure 3 shows a snapshot of the Twitter stream during this lesson. Specific examples from Fig. 3 are used to elaborate points in the discussion.

The map in Fig. 2 depicts a number of individual students/pairs ($n = 16$) posting items without many exchanges among each other. This is clearly a response to the task assigned to them, where questions or comments to the curator were the suggested format for their tweets. Indeed, fifteen tweets were formed as a question ($n = 15$) addressing @MoLtrial or @MuseLearn. They were all related to the museum and its exhibits/galleries (Fig. 3, e.g. t4 and t7). Students' tweets sought to get a personal

Table 2 Data from Twitter during the live communication with the museum curator

Categories		Number of tweets (total = 40)
Time	During lesson	34
	Beyond lesson (outside classroom)	6
Type of tweet	Original Tweet	34
	Retweet (RT)	2
	Direct reply	4
Task (i.e. according to instructions/question)	On-task	23
	Off-task/Contributing 'noise'	11
Hashtag (i.e. #oag1, #moltrial)		5
Addressing another user (incl. username or name in tweet)		30
Acknowledge group's names (collective task)		8

Note 1 @MoLTrial and @MuseLearn's tweets not included in the table
Note 2 Categories not mutually exclusive

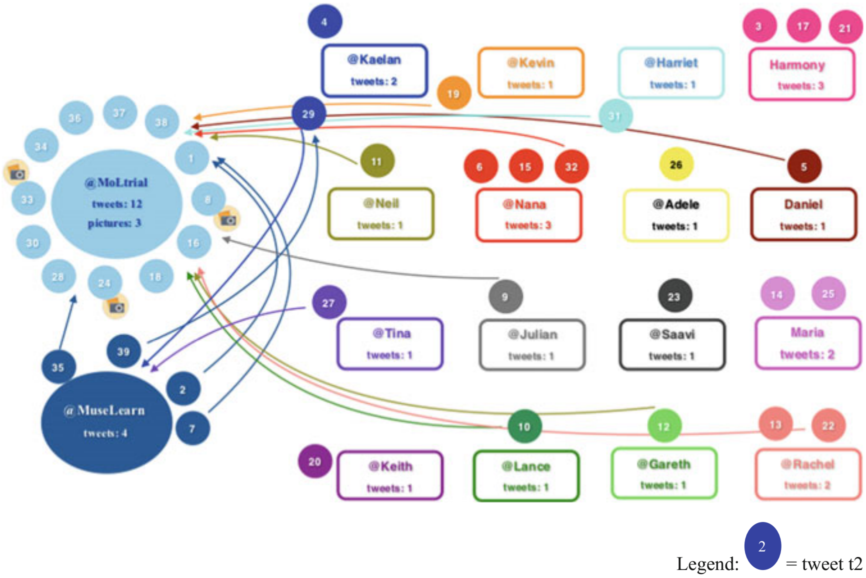

Fig. 2 Map of pre-visit lesson: 'Live' communication with a curator

opinion/response from the curator (Fig. 3, e.g. t3) or actual information to their questions, while three questions referred specifically to learning gains and links to schoolwork (Fig. 3, e.g. t1 and t5). It is noted that questions such as '@MoLtrial is there some modern things as well as the old things?' are seen as related to the perception of museums mainly displaying old objects. Tweets posted by the curator were topic-specific

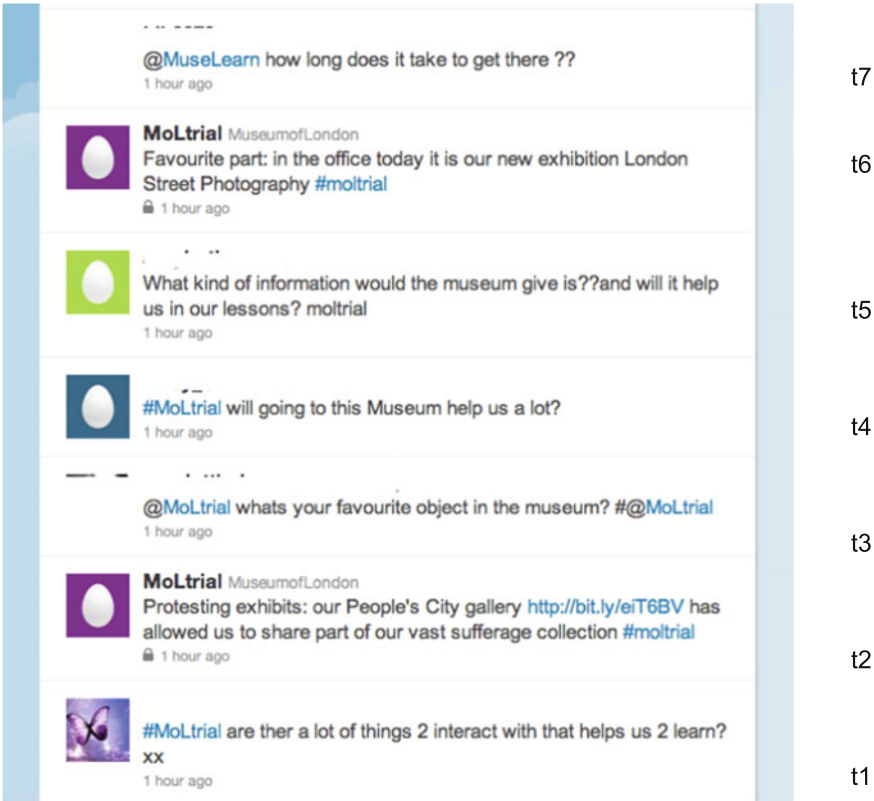

Fig. 3 Snapshot of the Twitter stream in lesson: live communication with a curator

(Fig. 3, e.g. t2), as well as demand-driven, meaning the curator was responding to questions posed by students (Fig. 3, e.g. t6). Only one tweet referred specifically to technologies (e.g. '@MuseumofLondon is the technology in the museum good and an easy way to give information?') and another one was linked to the topic of the visit (e.g. '@MoLtrial in the museum what are they key protesting exhibit's? And how in depth do they go? Like how did the methods affect other people?'). A few tweets expressed impressions about the museum and were overall positive (e.g. 'from what I have seen of the museum from the website and the video it looks okay!!!!!!!').

In the interview, a question was posed to enquire how the participants viewed the live communication with the curator. Seven students ($n = 7$) responded to this and all agreed that it was a very positive experience. Three themes emerged: the first points to this activity as *making the strange (i.e. museum) familiar* ($n = 6$), as indicative in the following: 'you had more of an inside to what was going to be like at the museum' (Kaelan). The second theme is related to *bringing an expert* in the classroom ($n = 2$); 'someone with… huge knowledge of a certain subject' (Kevin) and a person who could express 'his personal opinion as well as the facts' (Neil).

The third theme is related to the *instant nature* of the communication enabled by Twitter. Many students ($n = 4$) appeared to appreciate the live and instant form of communication where 'you get to ask questions… and he answered back to us straight away' (Maria). Engaging in live communication through Twitter is seen as shifting students' views about museums, as indicated in the following:

> The essence is that museums are big and they are unapproachable, while Twitter made them more approachable and like friendly… and it was easy to ask stuff… you know when you are emailing someone, but it's not instant messaging… kind of thing that you are talking to a wall sometimes… (Nana, Interview Data Extract).

Further to these points, a few interviewees ($n = 2$) referred to issues of managing this activity, e.g. size of the network, number of posts, belated replies, which are arguably challenges in employing microblogging in the classroom context during live communication.

During the interview with the teacher, a similar question was posed for her to provide her perspective on the lesson involving live communication with the curator. As in students' responses, the teacher also viewed this lesson positively and her response aligned with the themes mentioned above, namely that this lesson was seen as preparing the students for the visit and that it provided an opportunity for students to talk to an expert other than their teacher. Finally, the teacher found that enabling co-location and synchronous communication through technology—where the students 'were doing it at the same time and they were able to talk to someone who wasn't there…'—was a valuable experience for her students.

4.2 Pedagogy #2: Temporal and Spatial Arrangements (Visit)

During the visit to the MoL, the students had to follow pre-defined trails across the three Galleries of Modern London. Instructions about the trails and the activities for each gallery were provided in a worksheet, a common strategy used during school visits, usually serving the role of 'advance organisers' (Kisiel, 2006), i.e. helping teachers and students to organise their visit. In this study, worksheets were used to facilitate and structure the students' engagement with the exhibits and the technologies, but also as a way to sustain some characteristics of museum visits that participants had in the past, thus keeping tension low, i.e. combine novel aspects of introducing technologies and traditional aspects.

The worksheet was seen as a key enabler of the mobilised visit. It was designed for the specific topic being studied (i.e. 'Equality and Beliefs') to provide a trail through an array of artefacts and orientation cues in the galleries and to facilitate students' encounters with objects and the technology. Importantly, it was designed to allow for different temporalities and spatial movement in students' exploration of the galleries: students were to work under different temporalities, encounter objects at different time slots and visit specific spaces periodically. For this to happen, the worksheets had different starting points and included closed and open-ended questions/prompts

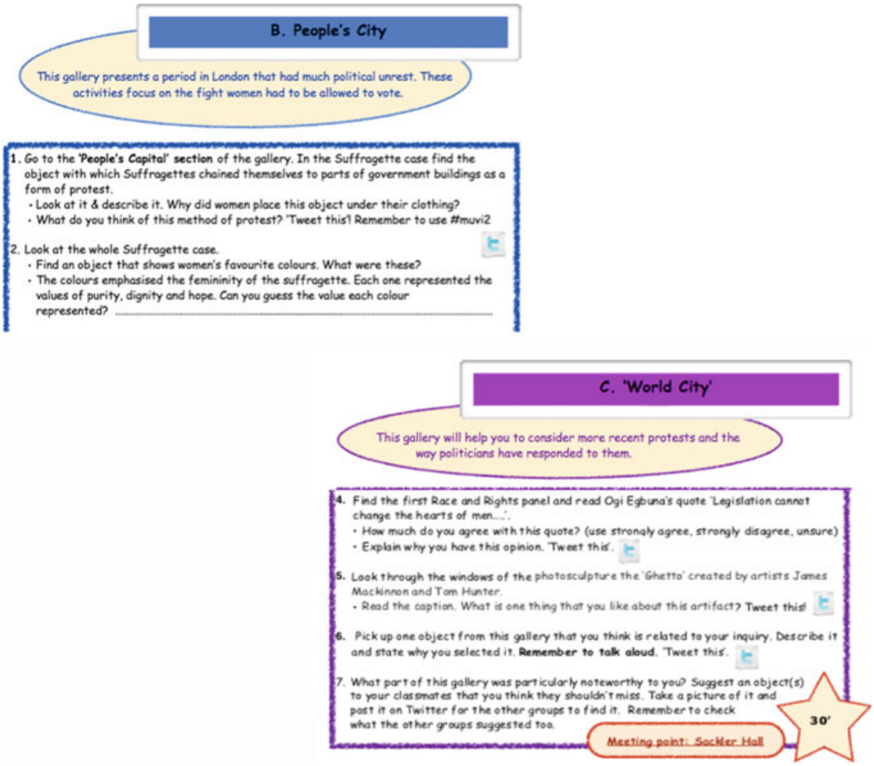

Fig. 4 Questions/prompts related to the activities at the Museum of London

(see Fig. 4 for examples of prompts) to use a 'controlled choice' effect (Bamberger & Tal, 2007) by allowing a gradual shift of choice over control in the activities in each gallery. Specifically, some tasks in each gallery were particularly structured to allow students an orientation period to familiarise themselves with space and scaffold observation with specific objects or to give students with little or no knowledge about museums or exhibits 'a place to start' (Walker, 2008, p. 116). Gradually, the tasks were becoming less structured and more open-ended, by letting the students choose where they would apply some of the tasks (e.g. 'Pick up any object(s) from this gallery that you think is related to your inquiry. Describe it and state why you selected it…'). Activities encouraging social learning were also included (e.g. tasks acknowledging other groups and aiming to foster group interactions). Multimodal responses were encouraged (e.g. visual and textual), and a variety of response formats were required (verbal, written). Also, explicit instructions to post their observations on Twitter were given by including the expression 'Tweet this' in tasks (see Fig. 4) to highlight the 'online space' dimension of this particular visit.

It is beyond the aims of this chapter to provide a closer examination of students' interactions as they unfolded in the museum. It has been shown elsewhere (Charitonos et al., 2012) that students were engaged in joint activity and had conversations in both a physical and an online space, and despite the complexity of experiencing an online space in the context of a museum visit, the online space also enhanced the social dynamics of the visit with students sharing an 'interconnected opinion space'. The example provided in this section suggests that this was facilitated because the worksheet brought together activities, tools, interactional moments and pedagogic considerations to make use of technological affordances in a formal visit to a museum.

4.3 Pedagogy #3: Engaging Learners in Active Learning: Presentations and Peer Review Activity (Post-visit)

The main task during three post-visit lessons was to create a presentation to address the inquiry assigned to each group during the visit (see Sect. 3). The first two lessons took place in the school's Web-enabled ICT suite, where the students had access to a range of resources (i.e. photographs in a Picture Pool, notes taken during the visit, the Twitter stream) to use in their collages. They were also prompted by the teacher to prepare an oral speech to frame these. The focus of this section is on the third post-visit lesson in the classroom, which further to group presentations also involved a peer review activity over Twitter (see Table 1 and Fig. 1).

The analysis primarily focused on examining whether tweets and photographs had a role in the development of the students' meanings and making connections across settings (see Sect. 3.4). This point is illustrated here by drawing on a collage that shows how a group of students reused resources they generated during the visit. What is shown in Table 3 is a photograph captured by this group during the visit that depicts an image of a black woman by a house's main door, on which, presumably, white people wrote 'Keep Britain White'. This photograph was reused in the group's collage (Table 3, Visual/Textual Mode row). In the context of the group's oral presentation, the photograph was called 'a white poster' (Table 3, 'Oral Mode' row) and served as a sign of a peaceful protest, which however presumably contradicted the students' own beliefs (see Oral Mode row). Notably, a similar judgment was expressed in a tweet posted by this group during the visit, also included in the bottom row in Table 3.

Overall, the analysis of all the presentations showed that photographs taken during the visit and to a lesser extent the tweets were used as resources in creating the collages. Students were able, to an extent, to select, re-remix and reinterpret resources collected in the museum and appropriate them to the context of their inquiry. Nonetheless, it was shown that out of the seven groups, three groups addressed their inquiry to some extent and three groups acknowledged them, either by referring to them in their oral presentation or by including them in the collage. Indeed, the diversity observed among the collages (also evident in the tweets in Table 4), both in terms of content and quality, is illustrative of how well students addressed the challenges which arose during the visit and the post-visit phase.

Table 3 Example of a group presentation

Collage/Frame B	
Visual/Textual mode	
Textual mode	This is actually a protest because someone is trying to get the view across. This was in the time when 1975 when black people where trying to get equality
Oral mode	(the key of bringing the white) poster, it's sort of—it's still…protesting, it's not physical like—it's a peaceful method, it's not the best type of method for some people, but people still, they are still protesting because someone doesn't agree with what people are saying, doesn't what to do what people, other people say and trying to get their view across, well in 1975 where black people are trying to get (vote)
Resources	
Photographs from 'Picture Pool'/online	
Tweets by Group 4	t64: #muvi3 the protest with the 'keep Britain White' this is a protest not a good one but someone is still trying to say something

Table 4 Exemplary tweets associated with the peer review activity

Criteria	Tweets
Focus of presentation/Overall comment	• #bestcollage [Group 4] a lot of text but it was relevant and images went with text. Overall really good a bit slow though xx • #bestcollage [Group 1] had way too Many pictures of random objects no information. Over all quite poor
Relevant information	#bestcollage really good, good captions and relevant text! Very emotive and relates to the images xx
Appropriate photographs	• #bestcollage [Group 1] they had loads of images but they weren't that relevant and not enough text and info xx • Good pictures and got the message across

Language is kept as in original posts by students

A parallel activity to the group presentations was the review of each other's presentations (excluding their own) and sharing of this review on Twitter by using the hashtag #bestcollage. A facilitated discussion by the teacher led to setting a few criteria for the peer review activity such as focus of the presentation, relevance of information provided and appropriate photographs. Each group had an iPhone (in total seven iPhones) and a member of each group logged into Twitter with his/her account. Table 4 provides examples of tweets that were posted during this post-visit lesson. In total, thirty-seven tweets ($n = 37$) were posted during the peer review activity, and importantly, no 'off-task' tweets were generated, which marks a difference to the pre-visit activity with the curator (Example A). All the tweets posted acknowledged the criteria set at the beginning of the lesson. Table 4 provides some exemplary tweets posted during this lesson.

In the interview with students, a question about the post-visit activity was posed and all ($n = 11$) students responded positively to this. The themes of *sharing and allowing multiplicity of perspectives* as well as *addressing an audience* were recurrent ideas among students, indicated by the following:

> we had to… like create it and make something just more than just pictures. You had to make someone think! (Nana, Interview Data Extract)

In response to the same question, the only criticism expressed was related to other groups' performance in this activity because '[they] just (flipped) the pictures and no information at all. So, we couldn't really learn from theirs' (Neil). This response relates issues of value to 'authority', i.e. providing some specialist knowledge of objects seen, experience worthy of respect or interpretations that would enable the students to learn or feel more about objects beyond the museum itself.

5 Discussion

The study presented in this chapter is concerned with the ways that Web and mobile technology can be used in the classroom and beyond for the learners to benefit from the crossover between formal and informal learning experiences. The aim was to provide an approach drawing on a well-implemented study in specific learning settings in order to turn the aspiration of crossover learning into a more grounded and practical activity.

The first question this chapter considered was:
How does technology shape and/or change pedagogical approaches to mediate crossovers between settings, practices and experiences?

The chapter provided empirical evidence from a study that was realised as a series of learning events, embedded in a range of pedagogical practices and integrated within other learning events, building on them and contributing to their outcomes. As such, mobile learning activities were seamlessly integrated with other types of learning activities, and interactions were not restricted only to interactions with a mobile device. Rather, drawing on the mobile pedagogy framework, the use of mobile devices was carefully considered as part of experience where they bring the most value based on their potential (e.g. Example 1: Web-enabled ICT suite at school and Twitter were used to bridge the two spaces). Further to this, the activities performed in the classroom and the museum were compatible with and relevant to activities that are performed in those spaces (e.g. Example 3: mobile devices were used for peer-to-peer interactions).

As illustrated in the first example, the pedagogy involved 'live learning', namely synchronous communication among an expert and young people located in two different settings. This aspect of teaching was enabled because of affordances provided by the technology, with evidence showing that Twitter was used as an instant feedback tool (Kassens-Noor, 2012) and a tool to ask questions. However, the 'instant' nature of this communication that was particularly valued by students and the teacher also pointed to the challenge of tracking and responding to a flow of tweets in real time. For example, delays in responses were observed, some questions were missed whilst a pattern of a single distributed conversation along a few intermittent, loosely joined dialogues between users was revealed in the analysis, as illustrated by the visual representation provided in this chapter. The latter could be partly explained due to the way the task was described to students, i.e. ask the curator. Further to this, it could be argued that the content shared between the curator and the students was not particularly specialised or interesting and the language used could be seen as resembling the ways young people normally employ in social media. Indeed, as others have argued (Crook, 2012), a point that needs careful consideration in introducing Web 2.0 technologies in K12 education is the tension that might occur between students' informal uses of such tools and the rather more formal aims and activities of teachers. Yet, before imposing a 'schooling perspective' in the use of such tools, careful consideration is needed as it might reinforce established views regarding where and when one is learning, and it might also reveal lack of awareness about the learning purpose this type of communication invokes, i.e. an active and informal, facilitating peer-to-peer interaction and enabling connections with formal classroom education.

The second example involved making use of a chapter-based resource, commonly used in school visits to museums to give students explicit tasks to complete. Worksheets in general provide with opportunities for enacting tailored pedagogical structures for specific themes. For example, in the study presented in this chapter, students visited a city museum with galleries devoted to topics such as women rights and black civil rights. By design, the study's worksheet was intended to facilitate engagement with the content at the MoL and the technology and to focus that engagement towards specific pedagogical goals. As shown in this chapter, specific emphasis was placed on the design of the tasks given to students, also taking into consideration pedagogic concepts, such as different temporalities and spatial movement in students' exploration of the galleries, student's choice and opportunities for immersion in different types of learning spaces (online, face to face). Finally, it is noted that the worksheet was a resource well integrated into this series of learning events as it built upon the classroom activity before the visit and supported activity during the visit and follow-up afterwards. As a result, it brought together activities, tools, interactional moments and pedagogic considerations to exploit technological affordances in a formal visit to a museum and mediate crossovers between practices and experiences, and as such, its combination with a microblogging platform provides a practical and promising approach for museum visits.

The final example drew on the pedagogy of active learning by creating visualising, exploring, sharing and presenting knowledge through artefact creation (Freeman et al., 2014). This is aligned with the mobile pedagogy framework and reinforces the idea of allowing time post-visit to reflect and share learning. What technology enabled in the context of this activity was the sharing and visibility of ideas as well as raising awareness of others' opinions and learning. The significance of the peer review activity lies in that it not only verified that Twitter can give immediate feedback (Ebner, Lienhardt, Rohs, & Meyer, 2010) but also that tweets can capture 'live thinking' (Ravenscroft, Sagar, Baur, & Oriogun, 2008) and help students 'document their experience' (Ebner et al., 2010) while attending these presentations. Importantly, it showed that the use of Twitter in this context brought an awareness of an 'audience'—students credited and could value and attribute particular weight to tweets or presentations, especially if these were seen as enabling them to learn more. Yet this activity also raised a number of challenges: (i) firstly, it involved the students evaluating which aspects of their visit experience, recorded as photographs, tweets or notes in the worksheet (or not recorded) were relevant and appropriate in creating their collage—a challenge also reported elsewhere (Vavoula et al., 2009). The large number of images along with lack of recorded relevant contextual information for each of them or the quality of the online discourse proved to be problematic in this process; (ii) secondly, it involved students in deciding how to design the presentation for a particular message to be clear and accessible to their audience. It was noted that the visual mode was the predominant one, showing that using device features and taking pictures in the visit had been of particular value for students as it allowed a different way of engaging with objects; and (iii) finally, addressing an inquiry in this context was a demanding activity and highly dependent on familiarity with the process, the approach each group took during the visit, as well as students' skills. Students were engaged in a novel learning activity, and as such, the methods to perform the inquiry and the use of the technology itself as well as skills to craft the microposts and communicate were being developed in the settings over time (Coughlan, Adams, Rogers, & Davies, 2011). Similar to an observation by Rogers et al. (2010), a point that requires attention in designing crossover experiences is the disparity between students who can, for example, draw on their experience and distribute ideas and interpretations in their tweets and others who find this transition between their experiences of the physical environment and higher-level ideas and abstractions challenging. As shown, this led to a few participants in the study questioning the quality of the content generated or being critical towards other students' efforts.

The second question this chapter considered was:
How can we divert attention from technologies to focus on creating pedagogical strategies to exploit the use of seamless environments for teaching and learning?

At the outset of this study is a belief that to understand and enable crossover learning, then learners and teachers, and their situated social practices should be our point of departure instead of what is technologically possible. This is well aligned with a recognition that one of the major challenges of today's education is not about using the most advanced technology or finding the best ways for knowledge delivery, but rather designing learning environments that respond to students' lives and reconfiguring spaces and places of learning to address the disengagement and disconnection from formal education that is experienced by an increasing number of students (Kumpulainen & Sefton-Green, 2012, p. 9).

The three examples provided in the chapter highlight pedagogic practices and point to the role of the teacher in influencing how technologies were used in the classroom. As David Guile puts it, most technology-enhanced gains in learning and achievement 'occur primarily because teachers have designed new contexts as well as new learning processes to support learning with [digital technology]' (cited in Reynolds, Treharne, & Tripp, 2003, p. 152). The study presented in this chapter took place over considerably prolonged period of time for the researcher to cultivate the relationship with the teachers and gain a greater understanding of the research context. Over this period, it became clear that the teacher needed ongoing support by the expert researcher as well as the researcher's involvement in getting things set and going, both during the design and implementation phase in the classroom and the museum. What is more, it also became clear that the use of technology did not make the classroom environment less complex. The evidence points to the classroom dynamics and context of the activities being constantly in flux due to the use of the technologies. For example, having a real-time feed at the core of the lesson design meant that the students' attention was distributed between multiple channels of communication and various resources and the context of learning became 'unpredictable' (Elavsky et al., 2011) and less constrained. Indeed, despite designing lessons for a known purpose and physical setting, the use of microblogging and the unpredictable nature of the real-time feed impacted on features well established in a classroom. There was an increasing need for the teacher to manage the learning activity and the technology. Whereas this may provide opportunities for new teaching (and learning) practices to be developed, it might also require developing practices for better understanding phenomena and features at play. For a teacher, this might be an 'additional burden' (Sharples, 2015). The argument often presented to the teachers when approached to take part in TEL studies is that they only need to carry on with their usual practice and the technology will do the rest. In hindsight, for teachers to exploit the use of seamless environments for teaching and learning, the TEL research community needs to be mindful of the implications technology has on the teacher's workload, and as others' have argued previously (Littleton, 2010) to provide the teachers with support, time and space to explore the associated implications of technologies for their pedagogy and practice.

Considering the reality of the modern classroom and the demands on the teacher, this chapter points to a need to gain a richer understanding of the many activities a teacher and students are asked to engage with, when managing and using complex technologies in a learning setting. This is consistent with Sharples (2013) who argues that in order to deliver on the promise of enhancing learning while reducing (or not greatly increasing) the demands on the teacher, we should simplify some component of the complex system, e.g. easier to use technology, a simpler lesson plan or a simplified task. The chapter offers practical examples to illustrate how lesson plans can incorporate devices such as smartphones as tools for innovative teaching in ways that maximise the affordances of devices and incorporate these in pedagogic practices to allow for connections across contexts—well aligned to seamless learning perspectives. Importantly, the chapter puts forward that mobile pedagogies do not simply replace the old ones; instead, traditional and novel mobile pedagogies can live side-by-side in contemporary schooling.

6 Conclusion: Towards a Mobile Pedagogy for Crossover Learning

Today's technologies offer a great potential for purposeful integration of tools for broadening access to learning by extending traditional space-time configurations of schooling and crossing over school learning and students' lives, activities, tools and identities situated within and across formal and informal settings, including virtual spaces. This comes with challenges, which cannot be adequately addressed by narrow and product-oriented views of education and schooling (Kumpulainen & Sefton-Green, 2012). A few years back, Wong and Looi (2011) proposed that seamless learning requires a change in the culture of education to incorporate mobile learning into the curriculum. The question regarding how technology is integrated into the curriculum and how it is used to promote meaningful and productive learning within and across learning contexts remains. This chapter is making a contribution to this and calls for pedagogical innovation where the design of seamless learning environments for crossover learning experiences should not be device- or tool-specific, rather be based on firm pedagogical understandings, and blend of traditional and mobile pedagogies. Understanding and supporting the engagement of young people in learning and how it is enacted in the school classroom is vital, and it is important as a way of offering new perspectives on the possibilities of pursuing learning trajectories across events, situations, contexts and experiences. This chapter helps to build a more coherent clarity of the pedagogical approaches that support learning across contexts.

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Part III
Expositions and Experimentations of Seamless Learning

Chapter 7
Sensors for Seamless Learning

Marcus Specht, Limbu Bibeg Hang and Jan Schneider Barnes

1 Introduction

Augmented reality (AR) applications for education have developed fast in the last years and have been integrated with several other technological developments as sensors, wearables and mobile devices. The application of these technologies extends the notion of seamless learning with a focus on the seamless embedding of learning experiences in the current context of use (Oppermann & Specht, 2006). This chapter will specifically focus on the role of AR and sensor technologies for enabling new forms of augmented learning and training scenarios. Specht (2015) has already introduced the model of Ambient Information Channels (AICHE) as an underlying approach for connecting sensor technology, data aggregation and modelling, contextualized filtering and combination of data streams for personalized and context-aware learning support.

Specht (2009) has proposed that a key component for future seamless learning technology would be sensor technologies for linking real world and media activities as embedded and seamless displays. The role of sensor technologies in this context can be manifold: On the one hand, sensors enable the precise tracking of digital devices and user interactions in physical environments. On the other hand, sensor-based tracking solutions also form the basis for a seamless integration of visual or auditory augmentations for learning support (Schneider, Börner, van Rosmalen, &

[1] https://www.microsoft.com/en-us/hololens.

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Specht, 2015a). Educational AR solutions are often closely linked to the seamless and direct integration of augmentations into situated learning support (Börner, Kalz, & Specht, 2013). Furthermore, the rapid development of semi-transparent glasses such as the Microsoft HoloLens,[1] and mobile camera and tracking technologies, has supported the seamless integration of virtual objects into situated user interactions, environmental modelling and better lighting integration. Recently, several of the leading technology companies have released their own AR frameworks as ARCore[2] from Google and ARKit[3] from Apple or Facebook with AR Studio.[4] Based on these frameworks and more standardized interfaces, new opportunities for AR are developed by combining full body sensor tracking and different embedded, mobile and heads-up displays. The capturing of expert activities in collaborative learning solutions and the multimodal modelling of expert performance enables in situ performance training of novices in a variety of domains (Limbu, Fominykh, Klemke, Specht, & Wild, 2018). In the WEKIT project, wearable glasses and a sensor enabled vest are used to support experts in recording real-time training material and annotating it with audio and reference materials. These recordings can be used by learners to practise in situ AR feedback based on the deviation from the expert behaviour and a feedback logic presented in the next part of this chapter.

Considering the learning outcomes of AR, several studies have recently analysed the potential impact and usage of AR. Specht, Ternier, and Greller (2011) have proposed a framework for classifying educational AR according to the contextual information considered and the educational objectives of an application. In this framework, the analysis identified several educational objectives of AR that range from illustration, exploration, understanding, reflection, collaboration and performance support in context. The AR applications have been analysed according to different contextual parameters to link the augmentations to the user context. These context parameters are identity, location, environment, relation and time based on a model from context-aware computing (Zimmermann, Lorenz, & Oppermann, 2007). Figure 1 shows an overview of different example applications of educational AR classified in a matrix form.

The underlying logic of this approach is rooted in the Model of Ambient Information Channels (AICHE) by Specht (2009, 2015), in which AR is abstracted as dynamic media channels which are synchronized with the user context. In the AICHE model, users move through different learning situations, and media are aligned with their contextual shifts to be most effective for individual support and learning. AICHE describes four core processes in which sensor data is aggregated, is enriched in entity relationship modelling, is used for synchronization of different channels and user contexts and can also be used for framing with related situations. While the first two layers are mainly driven by sensor data available about the user context and the related media channels, the processes of synchronization and framing are mostly driven by the user interface and user interactions. In that sense, following the AICHE

[2] https://developers.google.com/ar/.

[3] https://developer.apple.com/arkit/.

[4] https://developers.facebook.com/products/camera-effects/ar-studio/.

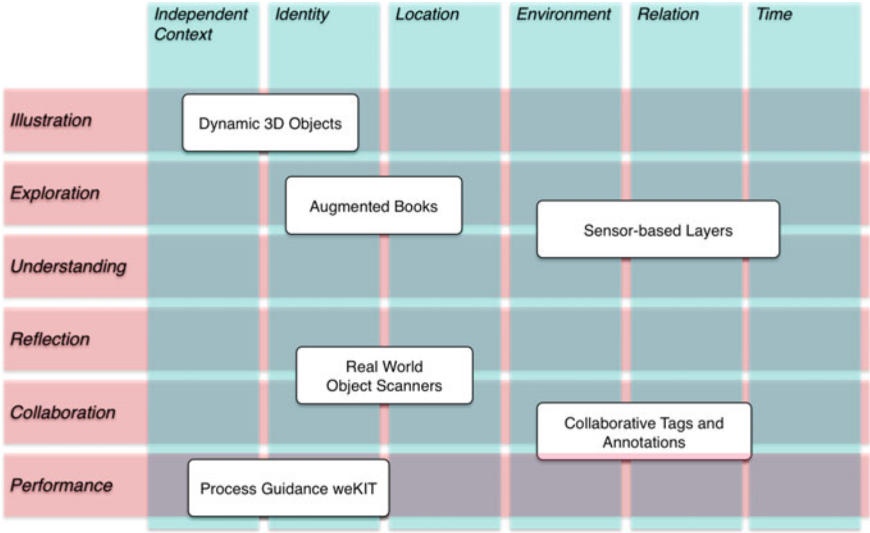

Fig. 1 Example applications of educational AR classified according to context and educational objective. Adapted from Specht et al. (2011)

model, AR can be seen as one user interface channel that can provide feedback and guide learners across different learning situations. Similar to mobile devices in an 1:1 setting, computing mobile AR devices provide specific opportunities for seamless and cross-contextual learning support (Specht, Börner, & Tabuenca, 2012) (Fig. 2).

In this paper, we would like to focus on two developments we consider as essential for better educational AR in the future and analyse some recent research accordingly. First, we foresee multimodal sensor tracking in the next few years to open up new possibilities for tracking of user activities on a micro-level based on sensors that go beyond human tracking possibilities. Second, the developments of mobile camera based in situ creation of environmental models enable an in-depth understanding of the learner's situation and the seamless integration of feedback and educational guidance in real-world training situations. Recent work in the field of augmented mirror feedback systems for training presentation has been shown to be successful for learning support (Schneider, Borner, van Rosmalen, & Specht, 2016).

We will next illustrate the link between the real world tracking of user activities and show how this data is used in educational AR systems. Thereafter, we will give an analysis of the possibilities of multimodal educational interventions in AR and how AR can be used for supporting guidance, feedback, formative assessment and expertise development in general. Our discussion is based on recent research projects and builds on a literature review and on technology design and development (Schneider, 2017).

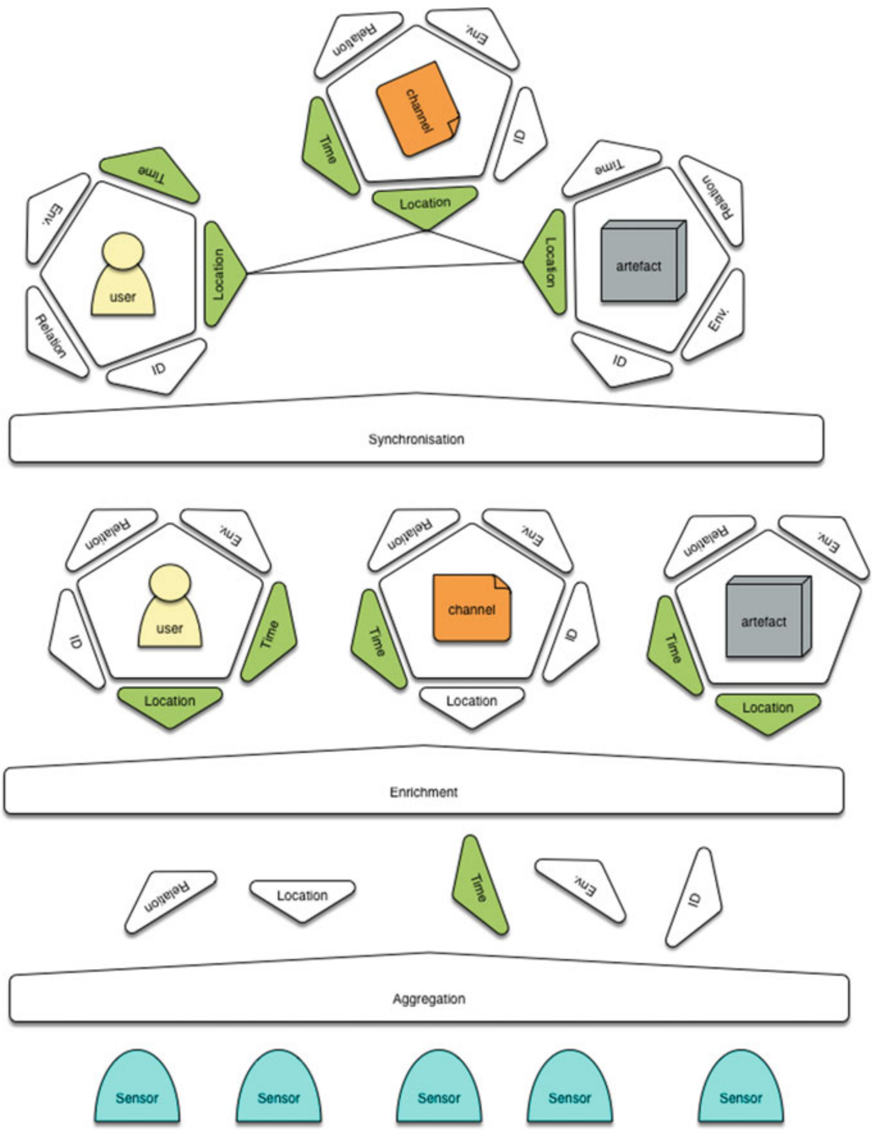

Fig. 2 Basic process and structures of the AICHE model

2 Linking Sensor-Based Interaction and AR

Sensor tracking is a key component of AR, linking the augmentations to the perceptual field of the user, and the registration process in AR is based on sensor tracking of the user movements. Therefore also feedback and learning support is essentially linked to sensors to track the user's activities but also to sensors for analysing and modelling the user's environment and environmental objects to be used with augmentations.

Schneider, Börner, van Rosmalen, and Specht (2015) have analysed the different sensor technologies used in educational settings in a systematic literature review. In their analysis, sensor data has been mapped onto tracking data and their educational functions in sensor-based educational systems (Schneider, 2017). Eighty-two sensor-based applications have been classified according to their strategies used for learning support in the cognitive, affective and psychomotor domain according to their strategies implementing formative assessment and feedback. The prototypes found in the literature review help the learners to identify progress according to defined goals, and this has been applied a lot in behaviour change approaches for healthy living, eating, eco travelling, as also fitness coaching and general health habits. Also, fine-grained feedback is implemented in a variety of examples to support learning with simple verification feedback, new attempts, elaborate feedback and reflection triggers. In their analysis, 23 sensors have been used in the different applications for sensing different low level (lighting, sound, positioning, temperature) as also high-level sensor information (physiological state, activity progress, emotional state, environmental changes). This sensor information has been used for contextual filtering of relevant support, user model acquisition, notification of state changes and personal reflection. They supported users with behaviour and activity reviews and monitoring, peer comparison and active data collection about environmental states. For psychomotor learning support, learners have been mostly tracked on fundamental movements and supported with psychomotor skill development (Table 1).

Based on this analysis, the authors have developed the presentation trainer prototype (Schneider, Börner, van Rosmalen, & Specht, 2014, 2015) and used this prototype to research different AR real-time feedback systems for learning to give presentations. Based on the sensors used in the prototype, different feedback could be given to end-users in an augmented mirror interface. The system used a Microsoft Kinect Sensor Array to identify higher level behavioural triggers while a user was giving a presentation in front of it. The behaviour tracked was body posture, use of gestures, voice volume, use of pauses, use of phonetic pauses and ability to stay grounded without shifting the weight from one foot to the other (Schneider, Börner, van Rosmalen, & Specht, 2015b). Feedback to the learners is computed on the basis of the measured behaviour and a rule-based system that identifies mistakes in the shown behaviour. The PT implemented different feedback generators for different feedback components, i.e. voice analysis as also body language and others. It supported learners with a freestyle mode and an exercise mode to train specific skills as reset posture, voice volume control, hands gesticulation, controlled pauses or leaning in while speaking soft (Schneider et al., 2015). For these different cases, the PT implemented different forms of real-time feedback (interruptive, corrective, content), as also personal reflection support with a learning analytics component. The presentation trainer prototype is a very good example for the close linkage of different sensor data and the learning support. Learning support based on sensor tracking can enhance the real-time feedback in suit as also the reflective analysis of a given

Table 1 Instructional design strategies based on sensor data

Sensor-based support strategy	Data aggregated from sensors	Sensor data used
Adaptation of supporting media to user context	Identifying user context for information filtering	NFC, RFID, GPS, Microphones
Adaptation of media channels to identity of users	Identification of learner and user modelling	EEG, Software sensors, NFC, Cameras, Heart rate monitor
Self-regulation support with sensor data for contextual reflection and change notification	Recording learner activities for review and reflection support	Accelerometers, Air pollutants sensors Cameras, ECG, EEG, gyroscopes, microphones
Behaviour overview and monitoring	Recording learner activities for review and reflection	Accelerometers, Barometer, Camera, Compass, GPS, Humistor, Microphone Software sensors, Thermometer
Peer comparison and motivational support	Social network and group collection of data	Blood glucose meter, Software sensors
Involving learners in data collection for authentic learning support	Data collection for situational context analysis	Accelerometers, Camera, Microphone, Thermometers
Real-time feedback for learners on fundamental movement	Movement tracking	Accelerometers, Cameras, ECG, Electromyography sensor, Gyroscopes
Real-time feedback and performance analysis	Physical activities	Heart rate monitor, Thermometer
Real-time feedback and performance analysis	Skilled movements	Accelerometers, Cameras, Force gauge, Gyroscopes

performance. In empirical evaluation of the presentation trainer, both approaches have been shown to be effective for learning gain and complex skill understanding.

Sensor data in educational systems is not only essential for giving real-time feedback and support assessment but also to build expert models by unobtrusively recording expert performance to generate expert models that are the basis for novice guidance and feedback. Sensors have already been successfully used in training by providing feedback based on expert data (Jarodzka, Van Gog, Dorr, Scheiter, & Gerjets, 2013: Schneider, Börner, van Rosmalen & Specht, 2017).

Sensors have the potential to capture diverse processes underlying expert performance and the environment in which the expert performs. This enables modelling these processes, which according to Collins, Brown and Holum (1991) is crucial for effective modelling. Capturing the process includes the possibility to make invisible aspects of the task visible (Idol & Jones, 2013). Therefore, we investigated how and if sensors can be or have been used to support modelling. Our intention is to sup-

Table 2 Recording of expert data for modelling

Approaches	Sensor used	Capture methods	Studies
Record of inertial data	Wireless inertial sensor, Depth camera, Infrared camera	Demonstration by the expert	Wei, Yan, Bie, Wang, and Sun (2014), Sun, Byrns, Cheng, Zheng, and Basu (2017), Kowalewski et al. (2016), Khan (2015), Li, Lu, Chan, and Skitmore (2015), Prabhu, Elkington, Crowley, Tiwari, and Ward (2017), Daponte, De Vito, Riccio, and Sementa (2014), Jang, Kim, Woo, and Wakefield (2014), Ahmmad, Ming, Fai, and Narayanan (2014), Meleiro, Rodrigues, Jacob, and Marques (2014), Chia and Saakes (2014)
Record of force applied	Pressure sensor	Demonstration by the expert	Araki et al. (2016), Asadipour, Debattista, and Chalmers (2017)
Record of eye tracking data	Eye tracker	Task analysis, Non-invasive recording of the visual search pattern	Sanfilippo (2017), Kim and Dey (2016), Ke, Lee, and Xu (2016)
Physiological data	EEG	Task analysis	Benedetti, Volpi, Parisi, and Sartori (2014), Asadipour et al. (2017)
Record annotations	AR and spatial space	Annotations placed in physical world Annotation of the captured data according to the steps in process	Li et al. (2015), Kowalewski et al. (2016)
Record audio	Microphone	Think aloud protocol and demonstration	Sanfilippo (2017)
Record video	Camera	Demonstration	Sanfilippo (2017)

port apprentices in modelling the expert performance by providing rich multimodal representations of the expert performance. In an analysis of 78 studies, the authors have identified 17 studies that have exclusively used experts as models for training (Limbu, Jarodzka, Specht, & Klemke, 2018). These are summarized in Table 2. The listed studies use sensors to record expert performance and the data to build expert models for an instructional approach to provide multimodal guidance and feedback or assessment.

Most applications use a demonstration performance by experts to record performances with camera-based and movement tracking data, also haptic sensor tracking is used in specific cases. Another group of applications uses sensors to do eye tracking of expert performance in combination with annotations or think aloud protocols. Also, basic video recording for demonstration purposes has been combined with audio recordings and documentation protocols. Besides recording the experts performance and behaviour the recording of the experts environment and cues from this environment can be highly relevant for sharing performances and understanding behaviour in context (Wagner & Sternberg, 1990).

In summary, sensor technology has been used extensively for real-time feedback and educational interventions as also for modelling expert performance in real-world activities. In the next section, we would like to analyse how educational systems have been designed to support seamless AR learning experiences and describe instructional design patterns used in these systems.

3 Design Patterns in AR Learning Experiences

Limbu et al. (2018) have recently performed a literature review on different approaches taken in AR applications for expertise development. In their analysis, the authors have found instructional design patterns for AR. An overview is given in Table 3. Based on the 4C/ID instructional design model (Van Merriënboer, Clark, & Croock, 2002), the instructional design patterns implementing the AR learning support have been analysed according to their focus on guidance considering learning task (augmented mirror, augmented path, interactive objects), giving supportive information (object enrichment, 3d models, x-ray vision, cues and clues, annotation, contextual information), guiding with procedural information (directed focus, highlighting objects, haptic feedback, formative feedback) and part-task practice (ghost track, summative feedback).

To cluster the results several approaches embed augmentations inferred from an expert performance into the perceptual field of the user's visual field as augmented paths, directed focus, cues and clues. Others augment the user perception with annotations and documentation or think aloud protocols of experts as think aloud or annotations. Yet others provide contextual information or alternative visualizations in context as object enrichment, contextual information, 3D models and animation and a last category enriches virtual embedded objects with new forms of feedback as real-time visual or haptic feedback.

A last category also gives alternative visualizations or the possibility to explore artefacts or expert's performances from different point of views as X-Ray vision or point of view video.

Table 3 An overview of analysed instructional design patterns in educational AR

Cluster	Instructional design methods	Description
Learning task	Augmented paths	Augmenting virtual information atop the physical world in a way which allows the trainee to guide his motion with precision
	Augmented mirror	Augmented display where the apprentice can track his/her body, similar to dance rooms
	Interactive virtual objects	Manipulate to practise on virtual objects with physical interactions
Supportive information	Annotations	Allow a physical object to be annotated by the expert during task execution (Similar to sticky notes, but with more modes of information)
	Cues and clues	Cues and clues are pivots that trigger solution search. It can be in form of image or audio. It should represent the solution with a single annotation
	3D models and animation	3D models and animations assist in easy interpretation of complex models and phenomena which require high spatial processing ability
	X-ray vision	Visualizing the internal process invisible to the eye for enhanced understanding
	Contextual information	Provide information about the process that is frequently changing but is important for performance
Procedural Information	Highlight object of interest	Highlight physical objects in the visual area indicating the trainee that the expert found that object of interest
	Directed focus	Visual pointer for expert determined relevant objects outside the visual area
	Object enrichment	Provide domain related information about the physical artefact which are crucial to the performance of the task from an expert's point of view
	Haptic feedback	Force feedback for perception and manipulation of authentic objects by means of haptic sensor, to provide feedback and guidance
	Feedback	Feedback is any formative or summative feedback that can be provided by sensors and AR. It could be provided in visual-auditory form and should allow meaningful information to be conveyed
Part-task practice	Ghost track	Providing deviation information for a part of the expert performance

4 Discussion and Conclusion

In this chapter, we focus on the relationship between sensor technology and the creation and design of instructional seamless media with a special focus on AR seamless learning experiences. We have identified several main purposes of sensor technology including real-time feedback and in situ reflection, recording of expert's performance for expert model building and design of in-depth feedback, formative assessment, as also sensor data recording of student performances for post hoc personal reflection.

The findings confirm the conceptual validity of the AICHE model considering the direct linkage of sensor information as well for building expert models and creating AR learning materials as also comparing expert data and student live data for real-time feedback. In addition, this chapter focuses on the definition of instructional design patterns especially used in educational AR applications and which link sensor tracking with the synchronization layer in AICHE for deliberate practice. The identified design patterns are described in detail in the weKIT reference framework (Limbu, Rasool, & Klemke, 2016) and have to be evaluated on their impact on learning support in future work. For implementing future prototypes and embedding them in senseful support, there needs to be more research on the specific use of AR in real-world learning situations and also empirical evaluation of different design options.

The contribution of this chapter is the extension of the conceptual AICHE model for applications making use of AR for seamless learning. Seamless learning is supported or enabled through the embedding of feedback and guidance in augmented displays in specific learning situations as well as through the connection of these learning situations (Specht, Börner, & Tabuenca, 2012). The chapter gives a variety of examples on how to make use of affordances of sensors and AR augmentations for the creation of expert models as also the deliberate student practice. The 4C/ID model gives us the flexibility and richness in design to combine the user tracking down to the level of eye tracking data with the power of sound instruction adapted to the individual. It also introduces a clear structure for designing feedback and instruction with embedded augmentations.

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Chapter 8
Designing Seamless Learning Activities for School Visitors in the Context of Fab Lab Oulu

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1 Introduction

During the last two decades, we have witnessed the flourishing of the Maker Movement. Maker is a term recently coined for individuals or groups of people who produce digital or tangible objects utilizing technological and digital tools. In particular, the making process includes constructing activities and related ways to fabricate real and/or digital artefacts using technological resources, including fabrication, physical computing and programming (Papavlasopoulou, Giannikos, & Jaccheri, 2017). As Dougherty (2012) notes, the Maker Movement, as such, was born with the publication of *Make*: magazine in 2005 and has created an interconnected network of enthusiasts who engage and collaborate with each other, sharing knowledge and tools.

Nowadays, maker culture has expanded from its traditional niches (people with interest in computers, programming and the digital world in general) to other, more general fields such as education, business and government. In parallel to the Maker Movement, MIT professor Neil Gershenfeld conceived the idea of Fab Lab in 2003. Gershenfeld (2012) presents a Fab Lab as a small-scale workshop equipped, at least, with a set of standardized equipment including a laser cutter, 3D printer, large and small computer-controlled milling machines and other materials (including components for moulding and casting and to build electronics). All the machines are connected by custom software.

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A Fab Lab is a component of the maker culture, which emphasizes the personal manufacturing of physical items (generally from scratch) by means of computer-controlled equipment (Colegrove, 2013). According to Milara, Georgiev, Riekki, Ylioja, and Pyykkönen (2017), typical activities in a Fab Lab include:

(1) Designing 3D and 2D parts. This incorporates the software and other tools which are utilized to design two-dimensional parts, such as those that are typically cut with a laser cutter, or 3D parts, such as those typically designed to be 3D printed.
(2) Prototyping with electronics. This includes hardware design (electronics schematics and layout design), including its fabrication and soldering the components.
(3) Programming. This incorporates the basic programming of embedded systems with a high-level programming language.
(4) Utilizing the tools and machines at the Fab Lab. This activity incorporates the use of Fab Lab infrastructure to make a particular prototype. It includes the utilization of the vendor's software to operate the machines.

The community is a foundational aspect of the Maker Movement in general and of Fab Labs in particular. The standardization of machines and processes enables an active exchange of ideas, designs, tools, materials and software, permitting the replication of any project at any Fab Lab in the network (Walter-Hermann & Bunching, 2014). Fab Lab is an example of a making context that does not resemble a traditional learning environment (e.g. a formal classroom). It promotes self-directed and collaborative work, creativity and problem-solving skills, as well as enhances computational literacy (see, for instance, Bevan, 2017; Blikstein, 2013; Blikstein & Krannich, 2013; Hsu, Baldwin, & Ching, 2017). However, while making is often touted as something new—e.g. in STEM education—it has deep roots in the theoretical thinking of Piaget, Vygotsky and Papert, and in pedagogies advanced by Froebel, Dewey, Montessori and others "who have argued for the centrality of materials-based investigations for motivating and advancing student learning" (Bevan, 2017, p. 75).

There is a growing number of research into the possibilities of maker settings in K-12 education. Based on the literature, research on the topic can be categorized into three types. First, theoretical approaches to the Maker Movement (Halverson & Sheridan, 2014; Martin, 2015; Vossoughi & Bevan, 2014); second, descriptions of and potential uses for technological tools for educational purposes (Blikstein, 2013); and third, discussions about the types of learning interactions experienced in those settings (Papavlasopoulou et al., 2017).

A literature review by Vossoughi and Bevan (2014) identified three main categories of educational maker activities, each with distinct purposes and audiences as well as overlapping features:

(1) *Making as entrepreneurship*. Fab Labs are one example of this category. They are fundamentally organized to support the production of things—to provide machines and other types of tools, such as 3D printers, that may not otherwise be accessible. Being in such a context fosters entrepreneurial mindsets in students who visit Fab Labs, and activities can be organized to provide supervised and (non)structured educative activities.

(2) *Making to support STEM workforce skills*. These programs, which generally take place in secondary schools, may resemble technology education or design-based learning programmes in that they are more focused on problem-solving than play. The curriculum is organized around project-based activities involving advanced tools such as 3D printers, vinyl cutters or welding equipment.
(3) *Educative making* does not depend on, though it can make use of, dedicated makerspaces like Fab Lab; instead it is primarily a pedagogical approach to engaging students in design/build activities that allow them to explore ideas, develop skills and understanding within multidisciplinary disciplines, and build a wide range of learning dispositions and capacities. This approach has become popular in informal settings such as libraries.

At the University of Oulu, we draw on this research and undertake studies to help us gain a better understanding of the processes at Fab Lab and in educational settings and to develop the most appropriate methodologies to produce consistent research data about these activities (e.g. Georgiev, Sánchez, & Ferreira, 2017; Iwata, Pitkänen, & Laru, 2017; Sánchez, Georgiev, Riekki, Ylioja, & Pyykkönen, 2017).

In continuation of these research efforts, we developed a pedagogical framework for seamless learning in the Fab Lab that features activities based on the multiple levels of interactivity that different tools, activities and the contexts enable. With the pedagogical design, we bridge individual and collaborative activities in the different contexts while also combining face-to-face with online activities. The aim is to use age-appropriate activities and appropriate tools as suggested by Blikstein (2013).

We begin this chapter by introducing the theoretical principles of the framework—computational thinking, computational making and design-driven education—that serve as foundational properties of a model designed to teach twenty-first-century skills (see Table 1). We will go on to illustrate the pedagogical principles of the model with a case study conducted in a primary school (K-12). The case study serves as an example of designing integrated traditional and maker activities in the Fab Lab context.

2 Computational Thinking and Computational Making in Makers Contexts

Many studies, starting from Seymour Papert's Logo programming language and Lego Mindstorms, showed connections between making and the learning principles of engineering, design and computer programming (Papavlasopoulou et al., 2017). Furthermore, the recent literature review "Empirical Studies on the Maker Movement, a Promising Approach to Learning" demonstrates that almost all the studies included into review had as their main subject programming or a combination of programming and math (Papavlasopoulou et al., 2017).

Grover and Pea (2013) argue that computational thinking (CT) is an important competency because today's students will not only work in fields influenced by

Table 1 Three frameworks that are used as theoretical lenses for the pedagogical design of the seamless learning activities

Twenty-first-century skills (Binkley et al., 2012)	Computational thinking [CT] (The College Board, 2013)	Computational making [CM] (Rode et al., 2015)
Ways of thinking • Critical thinking • Creative problem-solving • Learning to learn Ways of working • Communication • Collaboration (teamwork) Tools for working • Information literacy • ICT literacy Ways of living in the world • Citizenship: local and global • Life and career • Personal and social responsibility	• Connecting computing • Developing computational artefacts • Abstracting • Analysing problems and artefacts • Communicating • Collaborating	• Aesthetics • Creativity • Constructing • Visualizing multiple representations • Understanding the materials

computing but will also need to deal with computing in their everyday life. Yet the most cited rationale in the literature for including CT in K-12 instruction is the growing demand for citizens with computer science skills (Wilson & Moffat, 2010). In other words, CT can be considered an essential skill for twenty-first-century students (Wing, 2006).

In a K-12 context, several definitions have emerged for what CT entails in schools. Key in all these definitions is the focus on skills, habits and dispositions to solve complex problems with the help of computing and computers (see e.g. Voogt, Fisser, Good, Mishra, & Yadav, 2015).

Barr and Stephenson (2011) describe core CT concepts and capabilities that could be embedded in K-12 classrooms. They suggest nine core concepts for CT in K-12 education: (1) data collection; (2) data analysis; (3) data representation; (4) problem decomposition; (5) abstraction; (6) algorithm and procedures; (7) automation; (8) parallelization; and (9) simulation. On other hand, Barr, Harrison, and Conery (2011) define CT in K-12 contexts as a problem-solving process with the following characteristics: (1) formulating problems in a way that enables us to use a computer and other tools to help solve them; (2) logically organizing and analysing data; (3) representing data through abstractions such as models and simulations; (4) automating solutions through algorithmic thinking (a series of ordered steps); (5) identifying, analysing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources; and (6) generalizing and transferring this problem-solving process to a wide variety of problems.

Rode et al. (2015) critique these definitions because those consider desktop computers to be an environment of learning but does not embrace ubiquitous computing environments. They argue that Denning and Rosenbloom (2009) laid the grounds for a more comprehensive approach to computing by also embracing making. Rode et al. (2015) do, however, identify challenges in teaching pure CT skills in the context of maker activities: "as soon as we move from teaching computational thinking with a focus on desktop and software, to ubicomp and maker space … different skills are required. Knowledge of software is still critical, but so is knowledge of electronics, engineering and craft skills like sewing, drawing or carving … we call for a broadened notion of computational making (CM) as the starting point for future STEAM (Science, Technology, Engineering, Arts & Mathematics) education" (pp. 238). Their suggestions for computational making skills appear in Table 1.

Although the suggestions made by Rode et al. (2015) are good in the context of maker activities, a key aim of CT is to end up creating either tangible or virtual artefacts through processes which include phases such as abstraction, recursion and iteration during processing, and analysing project-related data (Barr & Stephenson, 2011). Based on Barr and Stephenson (2011), CT is a skill that can be implemented in different educational contexts, including languages and arts as well as STEM classrooms. In other words, CT can be used to augment human creativity (Voogt et al., 2015), in particular with the use of automation and algorithmic thinking. According to them, CT can be used for creating new forms of expressions in activities which support creativity and where different tools are being built. The College Board (2013) operationalized ideas about problem-solving and creativity in their "Computer Science Principles Draft Curriculum Framework", in which they introduced six CT practices, which are presented in Table 1. This framework will be used in this chapter to illustrate CT in the context of Fab Lab Oulu, because it has elements which can be seen also in the framework of CM and design-driven education.

Computational thinking activities are natural parts of maker culture, design and fabrication, and they can be seen as vital elements of thinking and working in the context of Fab Lab. By using CT as a framework for pedagogical design, it is possible to combine the development of skills and knowledge, which in school contexts are traditionally isolated and taught in separate subjects (Pitkänen, 2017). Through multidisciplinary, collaborative and problem-solving-based learning projects, learning twenty-first-century skills can be applied to the context of maker activities. One model for accomplishing this is described in the following section.

3 Design-Driven Education as a Model for Teaching Twenty-First-Century Skills in Makers Contexts

The information society we are living in demands that we develop skills to adapt to new ways of working, living, learning and thinking. We increasingly need new skills to manipulate information-based work tools; to search, analyse, evaluate and apply information; and even more significantly, to collaborate and solve problems together (Griffin, Care, & McGaw, 2012).

Numerous countries and organizations have defined their own recommendations and frameworks of twenty-first-century core skills (see e.g. ATC21S project, n.d.; European Union, 2006; OECD, 2005; and Partnership for 21st Century Learning, 2015). In this chapter, we will use the international Assessment and Teaching of Twenty-First-Century Skills (ATC21S, n.d.) framework to integrate twenty-first-century skills into pedagogical design (see Table 1). In this definition, ten future skills, called twenty-first-century skills, are divided into four broad categories: (1) ways of thinking, including critical thinking, creativity, problem-solving and learning to learn; (2) interactive and collaborative ways of working, including regulation of one's own and group activities and behaviours, (3) effective and meaningful use of tools for working and (4) ways of living—adopting responsible, participative, local and global citizenship in the world (Binkley et al., 2012). In addition to that, design-driven education in school contexts is also seen as one way to develop collaboration and communication skills (Halverson & Sheridan, 2014), increase students' motivation by engaging them in authentic learning scenarios (Cross, 2007) and promote creativity among learners (e.g. Hargrove, 2012; Lau, Ng, & Lee, 2009).

The core idea of design-driven education is that students and teachers participate together in the planning, implementation and assessment of learning projects (Hakkarainen, Mielonen, Raami, & Seitamaa-Hakkarainen, 2003; Nelson & Stolterman, 2003). The teacher's role is to provide support and guidance to the students and to encourage their collaboration for finding relevant and innovative solutions to the learning tasks. Students are expected and encouraged to find solutions independently. The community and experts outside the school are also seen as essential collaborators in stimulating learning and assisting students to solve various real-life problems. Furthermore, students' personal interests and expertise have an important role in creating an engaging learning experience (Gomoll, Keune, & Peppler, 2015; Heikkilä, Vuopala, & Leinonen, 2017).

In the maker context, a design-driven approach can be fitted into making, which emphasizes STEM skills (Vossoughi & Bevan, 2014). This view into maker activities are rooted in design and construction; learning activities emphasize the development of students' twenty-first-century skills, such as problem-solving, critical thinking and collaboration. This STEM approach has been championed by industry leaders because such educational programs are seen as good for developing the workforce of tomorrow by building young people's creative problem-solving capacities, as well as their technical design and engineering interests and skills.

In practice, designing and making in school contexts can be characterized as collaborative project work with concrete results (Heikkilä, Vuopala, & Leinonen, 2017). Many authors highlight that it is possible to integrate various subjects into design-driven projects, including art, crafts, technology and science (Leponiemi, Virtanen, & Rasinen, 2012; Rolling, 2016; Tan & Peppler, 2015).

In this chapter, design-driven education is used as a pedagogical lens for seamless learning design, while twenty-first-century skills are presented in the context of design-driven education in Oulu's Fab Lab. Pedagogical design is first discussed from the perspective of seamless learning and will be addressed again in detail at the end of this chapter.

4 How is Seamless Learning Present in the Context of the Fab Lab Oulu?

4.1 Example 1: Fab4School, An Example of No Seamless Learning Design

4.1.1 Context and Participants

Fab Lab Oulu, located in the University of Oulu in Finland, is a technology prototyping platform where learning, experimentation, innovation and invention are encouraged through curiosity, creativity, hands-on making and open knowledge sharing, similar to other Fab Labs around the globe. It is a space for university students, primary school pupils and other visitors to undertake studies or research-related projects, but it is also a space for the community around the university—namely, the citizens in the city of Oulu. The basic functions in Fab Lab Oulu are examples of making as entrepreneurship [as presented by Vossoughi and Bevan (2014)—see Introduction].

In addition to the global Fab Lab concept, there is a FabLab4School[1] project (a subdivision of Fab Lab Oulu) that aims to make Fab Lab activities known by all primary schools and high schools in the Oulu region. Specifically, it aims to get primary and secondary school pupils to become familiar with research and education in the field of technology and science at the University of Oulu. The main attractions of FabLab4School are (1) open doors to teachers and students on Fridays; (2) one-day workshops that aim of increase students' interest in Fab Lab activities; (3) longer-term projects, quite often consisted of multidisciplinary learning modules, and (4) summer schools.

A typical school visit to Fab Lab Oulu starts by discerning the preconditions for the students' future design activities. In the practice, context of the Fab Lab, materials and other possibilities are being presented to students by the instructors. Usually, there are three different templates for Fab Lab activities: (1) free design; (2) work on a given theme; or (3) realization of a concept which was started at the school. Pedagogical design of the FabLab4School activities is built around loosely structured activities which are minimally guided. The main idea is to foster learning by doing, where a facilitator provides scaffolding only when needed and gives hints to solve a particular sub-problem of the bigger problem-solving process. Teachers of the visiting groups are important facilitators; their excellent knowledge of their own classes allows them to support students with maker activities.

4.1.2 How is Seamless Learning Present in the Design?

The FabLab4School programming is quite minimal from the point of view of seamless learning design. Because the roles of the home and school are not explicitly

[1] http://fablab4school.fi/.

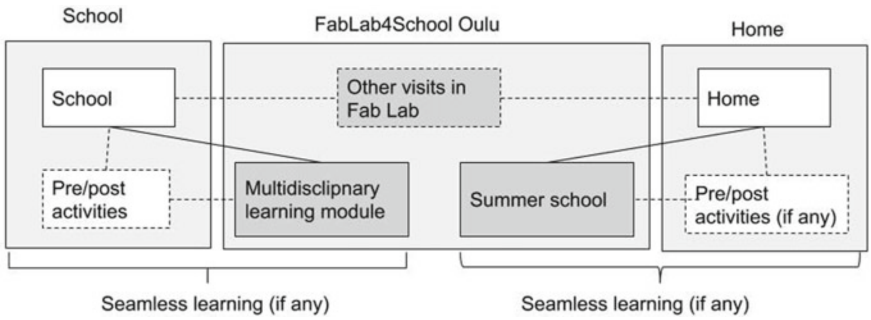

Fig. 1 Fab Lab activities without a detailed seamless learning design

designed in the context of FabLab4School Oulu, seamless learning activities are dependent on the visitors: How are the pupils prepared? Do the individual visitors have personal interests in making, tinkering, coding or other relevant themes? When youngsters who have received a position in the summer school receive their confirmation letters, do they prepare themselves for their programmes? What are the post-visit activities? Do the students continue maker activities on a smaller scale in their school? In Fig. 1 these questions are abstracted into visual form: pre- and post-activities are in dotted boxes because without explicit pedagogical design by the Fab Lab or the school there is no seamless learning (there are no explicitly designed activities which would integrate school, home and Fab Lab).

4.2 Example 2: A Fully Seamless Learning Design

Example 2 is situated within a multidisciplinary learning module project where activities have been divided between home, school and Fab Lab. What is particularly important in this example is that (1) the pedagogical design is created by students studying educational technology at a master's level in the University of Oulu and (2) these university students participate in maker activities with primary school pupils (see next section in more details).

4.2.1 Context and Participants

Participants in this study include 12 adult students from the Learning and Educational Technology (LET) master's programme in the University of Oulu, Finland, and 19 fifth-grade pupils (approximately 11 years old) selected from a public suburban elementary school (500 students) in the city of Oulu, in northern Finland.

The participating school has had two groups of pupils studying standard curriculum through hands-on maker activities in technology-oriented classes since 2014.

The aim of that program is to increase technology (or digital) literacy, students' motivation and twenty-first-century skills, such as creativity and problem-solving, by creating learning environments, which provide space and materials for students to learn and express innovation by building and experimenting with their own designs and solutions to open-ended, everyday problems. Maker and STEAM activities are built on four themes: (1) automation and robotics, (2) games and programming, (3) entrepreneurship and (4) product design and everyday technology.

LET's Research Unit has been offering postgraduate courses in educational technology studies for more than 20 years. The LET programme aims to develop the knowledge and competencies required in modern education—namely, skills for designing, conducting, assessing and analysing versatile learning situations, whether face-to-face or technologically enhanced. Moreover, many of the twenty-first-century skills that are required in today's working life are highlighted and supported in LET studies. Work/life connections are one essential feature of the LET programme.

Students in the LET programme participated in a ten-credit course, "Problem-solving case I" for two-and-a-half months. During the course, students learned how to apply theoretical knowledge to authentic educational challenges, how to design technology-enhanced learning activities in the makers education context, and how to work efficiently in a team to create a learning design. At the same time, students also participated in the eight-week, five-credit course, "Learning and Educational Technology." During the course, students learned how to use digital tools to support learning and teaching as well as for programming and electronics. One week of the course design was reserved for exploring the possibilities of the Micro:bit platform, which was chosen to be used as a development kit in the school project.

4.2.2 How is Seamless Learning Present in the Design?

In this example, pedagogical design covers multiple learning contexts: university (including the faculty of education and Fab Lab), home and school. In addition to that, there were four different groups of the actors in this example: university and school teachers, Fab Lab staff, LET master's programme students and primary school pupils. Masters' students had a task to design a pedagogical plan for the school pupils' project and also design a task to integrate into activities that they have designed.

This second example has many cross-contextual and cross-temporal trajectories for learning (cf. Looi et al., 2010). For example, masters' students had studied how to design an appropriate pedagogical model for design-driven learning—as well as how to use the Micro:bit development platform—in the context of maker activities for two months before the multidisciplinary learning module began. This temporal trajectory is visualized in Fig. 2 in the form of a line with arrows in both ends.

The contextual trajectory is explicitly presented in the same figure, but with a horizontal arrow. This trajectory starts with students who tinkered with Micro:bit at home and did some background explorations with the available material about the design task. In addition to assigning the usual homework, classroom teachers

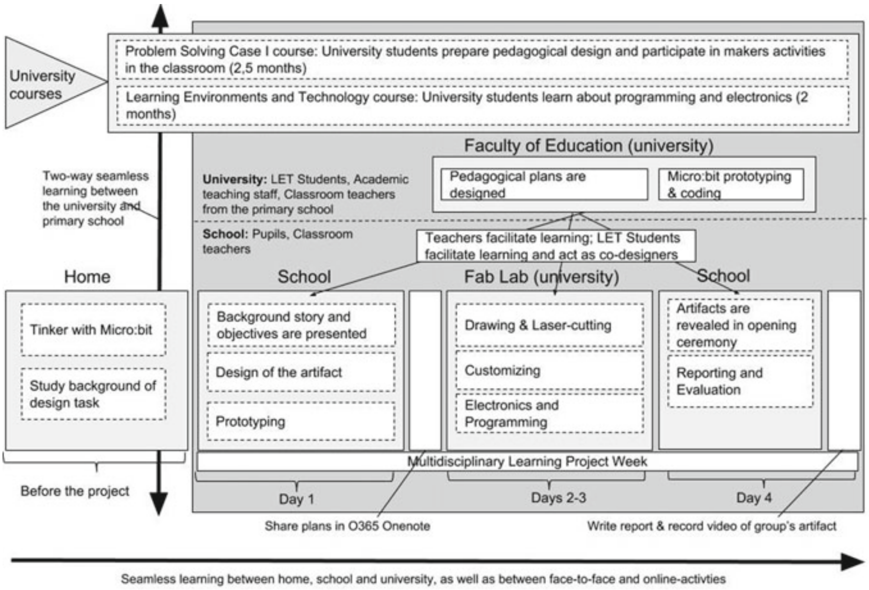

Fig. 2 Temporal and contextual trajectories for seamless learning in the context of the second example

also organized programming, measuring, technical drawing and electronics lessons before the multidisciplinary learning project began (see Fig. 2).

After these preparatory activities, the multidisciplinary learning module launched in the school. This was a linear design project where face-to-face and online phases followed each other during the four-day span of the module. In other words, a preliminary idea was invented on the first day at the school and was transformed into a tangible product in the context of the Fab Lab over the following two days. From the seamless learning perspective, students ideas were "reified and practised in authentic settings"—in this case, in the Fab Lab—to "later be scrutinized, enriched, transformed and/or challenged within the social learning spaces [of the classroom/Fab Lab], among others with relevant but diversified personal perspectives, knowledge and experiences [i.e. master's students, grade-school pupils, and teachers from the university and school] mediating the socio-constructivist discourse" on issues such as collaboration in the classroom, online tools and Fab Lab (Wong, 2016).

4.2.3 Detailed Description of a Pedagogical Model Using a Seamless Learning Approach: Education Master's Students and Primary School Pupils as Designers in Maker Activities

In line with the idea of design-driven education, LET students' work progressed through seven phases, all of which are described in Table 2. The first phase of design

Table 2 Task phases for learning about design-driven learning in the university context (first design round for LET students, 1.5 months duration)

Phases	Task for LET master's students, classroom teacher and university staff	Twenty-first-century skill(s)	Computational making/computational thinking
Phase 1. Defining the problem	How do we implement design education in a classroom?	Critical thinking Creative problem-solving Collaboration	CM: Creativity, understanding the materials CT: Connecting computing, analysing problems and artefacts, collaborating
Phase 2. Identifying the need	Why is it important to bring design thinking/ makers culture into primary school?	Critical thinking Creative problem-solving Collaboration Information literacy Life and career	CM: Creativity, understanding the materials CT: Connecting computing, analysing problems and artefacts, collaborating
Phase 3. Collecting the information	What are some earlier cases about design-driven education in school contexts? What knowledge and skills do pupils need to master and what do they already master?	Creative problem-solving Learning to learn Collaboration Information literacy	CM: Creativity, understanding the materials CT: Analysing problems and artefacts, collaborating
Phase 4. Introducing alternative solutions	How can this project be implemented with pupils? What are the alternative solutions?	Critical thinking Creative problem-solving Communication Collaboration Information literacy ICT literacy	CM: Creativity, understanding the materials CT: Developing computational artefacts, analysing problems and artefacts, communicating, collaborating
Phase 5. Choosing the optimal solution	Which solution is the most appropriate and why?	Critical thinking Creative problem-solving Collaboration	CM: Aesthetics, creativity, understanding the materials CT: Analysing problems and artefacts, collaborating
Phase 6. Designing and constructing a prototype and testing/piloting it	How do we construct the lesson plan in detail? How do we support school pupils with their programming and electronics activities?	Critical thinking Creative problem-solving Collaboration Information literacy ICT literacy	CM: Aesthetics, creativity, understanding the materials, constructing CT: Developing computational artefacts, analysing problems and artefacts, communicating, collaborating
Phase 7. Evaluation: Understanding what needs to be improved before implementation	What needs to be improved before the implementation?	Critical thinking Learning to learn Collaboration Communicating	CT: Analysing problems and artefacts, communicating, collaborating

took place on the premises of the Faculty of Education and Fab Lab at the university. In this phase, LET students had one-and-a-half months to plan and test the pedagogical design for the multidisciplinary learning module and to learn how to program and use the Micro:bit development kit in collaboration with both university and primary school teachers (see Table 2). In this phase, co-designing took place between university students and teachers from the University of Oulu and Rajakylä School.

Table 3 Task phases for the pedagogical design and implementation (second design round for LET students and learning activity for school pupils in the primary school context)

Day	Phases [physical setting]	Task [participants]	Twenty-first-century skill(s)	Computational making/computational thinking
1–3	Phase 0. Homework before project [home]	Practise basic programming with Micro:bit boards Research history of inventions and inventors Study how animals prepare for the winter [school pupils]	Critical thinking Information literacy ICT literacy Communication	CM: Understanding the materials, constructing, creativity CT: Connecting computing, developing computational artefacts, analysing problems and artefacts
1	Phase 1. Defining the problem, background story [school]	A class has a mascot but not a house for it, and the winter is coming [LET students, school pupils]	Creative problem-solving Collaboration Communication	CT: Connecting computing, collaborating
1	Phase 2. Identifying the need [school]	What do we have to do to get a house for the mascot? [LET students, school pupils]	Critical thinking Learning to learn Creative problem-solving Collaboration Information literacy	CM: Aesthetics, creativity CT: Connecting computing, analysing problems and artefacts, collaborating
1	Phase 3. Collecting the information [school, MS OneNote]	What requirements are there for the house? What materials do we need? What do we have to know, what skills do we have to master? [LET students, school pupils]	Learning to learn Creative problem-solving Collaboration Communication Information literacy ICT literacy	CM: Aesthetics, creativity, understanding the materials CT: Connecting computing, analysing problems and artefacts, communicating, collaborating
1	Phase 4. Introducing alternative solutions [school, MS OneNote]	What alternatives do we have for a house? [LET students, school pupils]	Creative problem-solving Collaboration Communication Information literacy ICT literacy	CM: Visualising multiple representations CT: Developing computational artefacts, analysing problems and artefacts, communicating, collaborating
2–3	Phase 5. Choosing the optimal solution [Fab Lab, MS OneNote]	Which alternative is the best one and why? [LET students, school pupils]	Critical thinking, Learning to learn Collaboration Communication Information literacy	CM: Aesthetics, understanding the materials CT: Connecting computing, analysing problems and artefacts, communicating, collaborating

(continued)

Table 3 (continued)

Day	Phases [physical setting]	Task [participants]	Twenty-first-century skill(s)	Computational making/computational thinking
2–3	Phase 6. Designing and constructing a prototype and testing/piloting it [Fab Lab]	How do we actually construct the house? [LET students, school pupils]	Creative problem-solving Critical thinking Collaboration Information literacy ICT literacy	CM: Aesthetics, creativity, constructing, understanding the materials CT: Developing computational artefacts, abstracting, analysing problems and artefacts, collaborating
2–3	Phase 7. Evaluation: Determining what needs to be improved before teacher's evaluation [Fab Lab]	What did we achieve? What should be improved? [LET students, school pupils]	Critical thinking Collaboration Information literacy ICT literacy	CM: Aesthetics, understanding the materials CT: Analysing problems and artefacts, collaborating
4	Phase 8: House opening ceremony, reporting and evaluation [School, Video, Padlet]	How do we present our house in the video clip? What do we write into our report? [LET students, school pupils]	Creative problem-solving Critical thinking Collaboration Communication Information literacy ICT literacy	CM: Creativity, visualising multiple representations CT: Developing computational artefacts, communicating, collaborating

The second phase of the activity was the implementation of the co-designed multidisciplinary learning module. Teachers, pupils and university students participated actively in the design and implementation of the project. The role of the teachers was to facilitate pupils' work while university students co-designed the problem-solution with primary school pupils (see Table 3 for detailed activities).

The students' primary task was to build a model house for a toy animal. These consist of several laser-cut plywood boxes customized and furnished by students. Each pair of students makes a plywood-box room and furnishes it with crafts materials. After that the students build an electric system in the room. The third-grade students learn basic electronics by building an electric lightning system in the model house with recycled USB wires, LEDs and switches. The fifth graders are tasked with designing and building a home automation application with Micro:bit development boards, servos, DC motors, LEDs, etc. The Micro:bit boards are given to the students in advance so that they have time to get acquainted with their programming interface.

5 Conclusions

During this century, technological and methodological developments in information and communication technologies have changed the ways in which people communicate, collaborate and learn in fundamental ways. Ubiquitously, present digital technology has changed our lives so that we are heavily influenced by computing—according to Barr and Stephenson (2011) today's students must begin to work with algorithmic problem-solving and computational methods and tools in K-12 schools.

It is not surprising that current generations of children and teenagers have generally good skills in using cognitive tools, such as computers, and smartphones and they are also quite familiar, for instance, with editing digital photos and creating web pages, but less than half of them can create something by exploration and fabrication technologies, such as do 3D designing, robotics or programming (Blikstein, Kabayadondo, Martin, & Fields, 2017).

However, Fab Labs are examples of engaging learning environments where participants "not only learn the target subject(s) but also come to understand the means for working with and creating knowledge (e.g. finding problems, representing or remodelling knowledge, locating resources, testing ideas through experimentation" (Lam et al., 2016, p. 1090). However, Papavlasopoulou et al. (2017) point out that "despite the interest in the Maker Movement and its connection to formal and informal education, there has been little research concerning the direction it is taking, the opportunities it could present for education, and why" (pp. 59).

While the original Fab Lab idea was conceived as a creative space for university students, and local inventors, nowadays there are a lot of networks, initiatives and projects which aim to support collaboration and creative problem-solving e.g. FabLearn Labs (USA), FabLab@School.dk (Denmark). The goal of some of the activities at the different digital fabrication networks is to engage children as quickly as possible in real projects, creating authentic context for learning. FabLab4School project in the context of Fab Lab Oulu is not exception in that sense. However, carefully designed teacher preparation programs and pedagogical designs are still under the preparation. This contribution is one part of the process where visits of the primary and secondary school pupils into Fab Lab Oulu visits are being designed to be more integrated, more meaningful and more engaging.

From that point of view, seamless maker activities described in this chapter, illustrate practical implications for designing the use of multiple learning contexts, learning tasks, participant profiles and tools to support design-driven education to teach twenty-first century-skills, computational thinking and computational making in Makers contexts. Therefore, by providing an explicit socio-technical example, this chapter can contribute to pedagogical practices when educators are considering how they could integrate Fab Lab activities with their primary school lessons and curricula. Seamless approach for makers activities can be seen as a integration tool for Fab Lab facilitators, primary and secondary school teachers and academic teacher educators. Interplay between theoretical sections and examples of the pedagogical design in this chapter illustrate how complex ideas of computational thinking, design-driven education and computational making can be integrated both into teacher education, primary school project and Fab Lab activities.

This case study was limited by the single-case design and the lack of empirical data collection and analysis. However, it also has been argued that research designs in the authentic contexts inevitably provide principles that can be localized for others to apply to new settings and to produce explanations of innovative practices (Fishman, Marx, Blumenfeld, Krajcik, & Soloway, 2004). Therefore, research investigations conducted in authentic contexts are still needed as a first step to understand these new opportunities in terms of learning interactions and collaboration that seamless maker activities can produce.

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Chapter 9
Supporting Seamless Learning with a Learning Analytics Approach

Noriko Uosaki, Kousuke Mouri, Mahiro Kiyota and Hiroaki Ogata

1 Introduction

In recent years, educational data mining (EDM) and learning analytics (LA) have grown around a joint interest in how big data can be exploited to benefit education and the science of learning (Baker & Inventado, 2014). Both have already made contributions to the learning sciences and to practice. The current trend suggests that this contribution will continue, and even increase in the years to come (Baker & Siemens, 2013). They also reported that researchers in EDM are more interested in automated methods for discovery within educational data; researchers in LA are more interested in human-led methods for exploring educational data (ibid). There are various kind of approaches in this field such as scanning through large datasets

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to discover patterns that occur in only small numbers of students (Baker, Corbett, & Koedinger, 2004; Sabourin, Rowe, Mott, & Lester, 2011); investigating how different students choose to use different learning resources and obtain different outcomes (Beck, Chang, Mostow, & Corbett, 2008); conducting fine-grained analysis of phenomena that occur over long periods of time (Bowers, 2010); and analyzing how the design of learning environments may impact variables of interest through the study of large numbers of exemplars (Baker, de Carvalho, Raspat, Aleven, Corbett, & Koedinger, 2009) (quoted from Baker & Siemens, 2013).

In the meanwhile, we have witnessed a growing presence of smartphones, tablets and other mobile devices for more than a decade. The wide range of mobile and ubiquitous technologies have enabled students to learn continuously across different contexts (Looi, Sun, & Xie, 2015; Milrad et al., 2013). We have developed a ubiquitous learning log system called SCROLL (System for Capturing and Reusing Of Learning Log) since 2010 (Ogata et al., 2014). SCROLL supports learners to record what they have learned in both informal and formal settings as a log using a Web browser and a mobile device and to share them with other learners anytime and anywhere beyond the limits of time and space.

One of the research issues in this chapter is how we can bridge eBook learning and real-life learning. In this study, we define "real-life learning" as an unplanned accidental learning which happens in an everyday life setting such as leaning a new word or phrases in the course of the conversation with their friends, reading articles on Facebook posted by their friends. In other words, the objective of this chapter is how we can connect learning in the cyberspace with that of the physical world using a learning analytics approach. So far, attention has not been drawn enough to this aspect.

In our study, we tackled the following research issues for the implementation of a successful seamless learning environment with learning analytics approach:

(1) How we can utilize the learning logs accumulated in seamless language learning system?
(2) How can we connect eBook learning with real-life learning?
(3) How can we enhance the students' real-life learning with learning analytics approach?

To address these issues, we have proposed a seamless visualization and analysis system called VASCORLL (Visualization and Analysis System for COnnecting Relationships of Learning Logs). VASCORLL analyzes and visualizes learning logs accumulated in a seamless language learning system. The system supports eBook learning and real-life learning by integrating the ubiquitous learning system called SCROLL and AETEL, an eBook system implemented on top of SCROLL. Our research questions are:

(1) Is VASCORLL able to enhance learners' learning opportunities? The degree of learning opportunities will be measured by the number of logs uploaded and relogged to the system. "Relog" function in SCROLL will be described later in subsection of SCROLL. By relogging, we can utilize accumulated logs in SCROLL.

(2) Does it facilitate finding "important words" in the seamless learning environment? "Important words" mean central words which link eBook learning with real-life learning. In other words, they were learned by many learners both through eBooks and real-life. VASCORLL enables linking eBook learning with real-life learning.
(3) Which centrality is the most effective in supporting learning in the seamless learning environment? Three types of social network analysis will be described later in the subsection of learning analytics.

The dependent variables for each RQ were (1) the degree of learning opportunities measured by the number of logs uploaded/relogged, (2) degree of facilitation measured both by the number of logs uploaded/relogged and the five-point scale questionnaire results, and (3) effectiveness of centrality, which was measured by the five-point scale questionnaire results. To answer these research questions, an evaluation experiment was conducted. The rest of this chapter includes related research on learning analytics and seamless learning. The systems SCROLL, AETEL, and VASCORLL will be described, followed by the evaluation of VASCORLL together with three types of social network analysis conducted under the full-seamless condition in the context of Japanese vocabulary learning at the university level. Lastly, conclusions and future work for the development of the seamless learning environment will be presented.

2 Related Research

2.1 Learning Analytics

There is no universally agreed definition of the term, "learning analytics (LA)." One popular definition states that learning analytics are "the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs" (Siemens, 2011). The biggest benefits can be pursued through the discovery and understanding of the data's hidden information (Siemens, 2013). In addition, LA aims for practical use based on learning mechanisms revealed by visualizing, mining, and analyzing vast amount of learning data (Ferguson, 2012).

Social learning analytics (SLA), a subset of LA, focuses on how learners build knowledge together in their cultural and social setting. In the context of online social learning, these analytics take into account both formal and informal education environments, including networks and communities (Ferguson & Shum, 2012). It puts forward presenting appropriate information to learners at the appropriate timing in real time.

Granovetter (1973) states that social network analysis leads to find the central relationships between individuals or clusters. Social network analysis is the process of investigating social structures through the use of network and graph theory.

Mazza (2009) also reported that information visualization such as network graph based on graph theory, 3D representation and map is often more effective than plain text or data. A network is created in terms of nodes and edges that connect nodes. Visualization and analysis methods are listed in Table 1, which are categorized based on social network analysis. Degree, closeness, and betweenness centrality are the fundamental measurement concepts for the social network analysis (Freeman, 1979; Latora & Marchiori, 2004). We aim to reveal the relationships between learners and learning logs in a spatiotemporal field.

Majority of network graph studies have focused on advantages such as good-quality results, flexibility, simplicity, and interactivity. For example, a network layout called "force-directed" uses the force vector algorithm proposed in the Gephi software, which is appreciated for its simplicity and for the readability of the network that helps in the visualization (Fruchterman & Reingold, 1991; Mathieu, Tommaso, Sebastien, & Mathieu, 2014; Noack, 2009). A network layout called "Yifan Hu multilevel" uses a very fast algorithm to reduce complexity (Hu & Scolt, 2001). The repulsive forces on one node from a cluster of distant nodes are approximated by a Barnes–Hut calculation, which treats them as one super-node (Barnes & Hut, 1986).

Table 1 Social network analysis

Algorithm	Formula (graph G = (V, E) with V vertices and E edges)	Details
Degree	$C_i^D = \frac{k_i}{N-1}$	Degree centrality is defined as the number of links incident upon a node. That is, it is the sum of each row in the adjacency matrix representing the network. N is the number of node, and k_i is the degree of the node i
Closeness	$C_i^C = (L_i) = \frac{N-1}{\sum_{j \in G,\, j \neq i} d_{ij}}$	Closeness centrality is that the distance of a node to all others in the network. d_{ij} is the shortest path length between i and j, and L_i is the average distance from I to all the other nodes
Betweenness	$C_i^B = \frac{1}{(N-1)(N-2)} \sum_{j \in G,\, j \neq i} \sum_{k \neq i,\, k \neq j} \frac{n_{jk}(i)}{n_{jk}}$	Betweenness centrality is that the number of shortest paths between any two nodes that pass via a given node. n_{jk} is the number of the shortest path between j and k, and $n_{jk}(i)$ is the number of the shortest path between j and k that contains node i

2.2 Seamless Learning

"Seamless learning" is used to describe the situations where students can learn whenever they want to in a variety of scenarios and that they can switch from one scenario to another easily and quickly using one device or more per student ("one-to-one") as a mediator (Chan et al., 2006). Mobile and ubiquitous technologies have been expected to foster shifting from classroom-based learning to the one that is free from time and space boundaries. Wong and Looi (2011) identified ten salient features of seamless learning: (1) encompassing formal and informal learning, (2) encompassing personalized and social learning, (3) across time, (4) across locations, (5) ubiquitous knowledge access, (6) encompassing physical and digital worlds, (7) combined use of multiple device types, (8) seamless switching between multiple learning tasks, (9) knowledge synthesis, (10) encompassing multiple pedagogical or learning activity models.

Uosaki, Ogata, Li, Hou, and Mouri (2013) described implementation guidelines for ubiquitous seamless mobile learning featuring the learning log system named SCROLL (System for Capturing and Reusing Of Learning Log). They analyzed how seamless the learning could be and categorized it into seven types according to the facilities being afforded. Their main foci in the guidelines are for language teachers to practice SCROLL-based mobile learning in their classes for both in-class and out-of-class learning according to their situation or conditions.

Milrad et al. (2013) provided an overview of five different seamless learning projects researched in Taiwan, UK, Sweden, Singapore, and Japan. Uosaki, Ogata, Sugimoto, Li, and Hou (2012) proposed a seamless learning system called SMALL (seamless mobile-assisted language learning) for English education at universities in Japan, suggested "link rate" to show how out-of-class vocabulary learning is linked with the in-class one and reported that the seamless learning group uploaded fewer words but learned more words than the non-seamless learning group. Meanwhile, Wong, Chai, Zhang, and King (2015) developed and evaluated a system called MyCLOUD (My Chinese Language ubiquitOUs learning Days), where they explored the integration of mobile and cloud technologies for self-directed, collaborative, and seamless Chinese language learning among primary students. They employed the TPACK (technological pedagogical content knowledge) framework as the basis of MyCLOUD development.

Our focus in this chapter is learning analytics approach under the seamless language learning environment. An effective language learning is characterized by the active and constructive production of thoughtful linguistic artifacts in authentic learning settings (Ellis, 2000). To provide effective language learning, it is necessary to bridge in-class learning and real-life learning. Most seamless language learning (SLL) studies so far had not considered the learning analytics perspective (Chai, Wong, & King, 2016; Uosaki et al., 2012; Wei, 2012). We believe that utilizing the collected learning logs lead to enhancing the quality of learning.

To support SLL from learning analytics perspectives, this study proposes seamless learning analytics to bridge eBook learning and real-life learning by analyzing and visualizing the learning logs collected in both settings. In the section entitled "SCROLL", this paper describes the seamless language learning for supporting real-life language learning.

3 SCROLL, AETEL, VASCORLL

3.1 SCROLL

Since 2010, we have been developing SCROLL (System for Capturing and Reusing Of Learning Log) (Ogata et al., 2014). SCROLL supports learners to record what they have learned in both informal and formal settings as a log using a Web browser and a mobile device and to share them with other learners anytime and anywhere beyond the limits of time and space. In this study, we define "log" as the objects uploaded to SCROLL with texts, images, videos, and so on. Figure 1 shows a log uploaded to SCROLL on the Web (left) and on mobile (right). Since the mobile screen is small, it is necessary to scroll down to see the whole description.

This ongoing project is still in progress with new functions being added to the system one after the other. Its functions are described as follows:

(i) Recording: The system facilitates the way learners record their newly learned terms on the server. For example, when a learner comes across a new term, while reading contents, he can upload it to the system with texts, images, video, or pdf files. Translation is facilitated by Google translate.
(ii) Recommendation: The SCROLL recommendation function works as follows: When a learner uploads a new word to the system, the system checks if the same log or related logs have already been uploaded or not and shows the related terms to the learner. Then the system links learners' new log with their past log. This recommendation function assists the implementation of

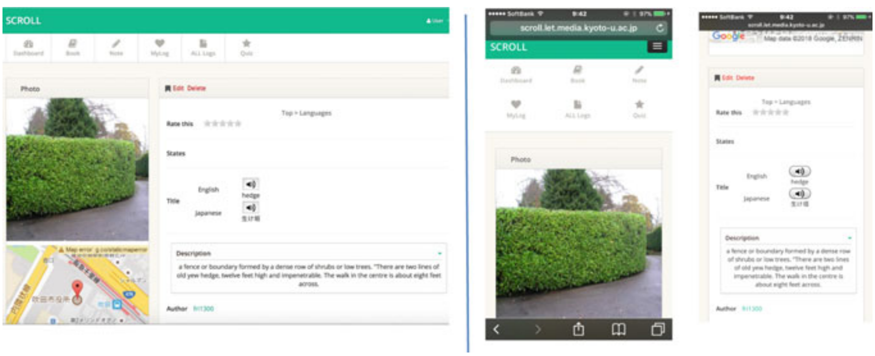

Fig. 1 "Log" sample of SCROLL, "hedge" on the Web (left) and on mobile (right)

seamless learning by linking e-textbook learning with learning through real-life experience, linking learners' present learning with their past learning, and also by linking a learner's learning with that of other learners.

(iii) Relogging: The relogging function assists with linking one learner with other learners beyond time and space. When a learner sees other learners' logs and finds them useful, he/she can "relog" them to make them his/her own logs just like the "retweet" function in Twitter. For instance, if they want to learn a new term which was uploaded by someone else, then they click "Click to relog" button. Then it appears in their "My Logs" page. Therefore, learners can obtain knowledge from others without having heard of or encountered all those words or concepts themselves. Using this function, knowledge can be shared instantly beyond time and space seamlessly, no matter whether it is informal or formal learning (i.e., seamless knowledge sharing).

(iv) Quizzes: It is reported that the quiz function is effective in reinforcing students' memory (Li, Ogata, Hou, & Uosaki, 2013; Uosaki et al., 2013). The quiz function also assists in linking their present learning with their past learning. Four types of quizzes (multiple-choice and yes–no quiz with images and texts) are generated automatically by the system. These quizzes are generated according to a learner's profile, location, time, and the results of the past quizzes they took.

(v) Reviewing: TimeMap proposed by Johnson and Wilson (2009) was implemented so that learners could review where and when they acquired their knowledge at a glance. It is reported that location information plays an important role in retaining memory (Baddeley & Hitch, 1974). It provides learners with better opportunities to review their learning.

3.2 AETEL (eBook System)

AETEL (Actions and learning on E-TExtbook Logging) is an additional function implemented on top of SCROLL (Kiyota, Mouri, Uosaki, & Ogata, 2016). It runs inside SCROLL. As shown in Fig. 1, AETEL consists of database and EPUB (Electronic PUBlication, one of the eBook formats) File Folder. It has two functions: (1) EPUB-viewer and (2) MyLearning. AETEL EPUB-viewer shows the learners their selected EPUB file from EPUB File Folder (Figs. 2(1) and 3(left and right)). Learners can add logs on EPUB-viewer to SCROLL database (Fig. 2(2)). While learners are reading EPUB on EPUB-viewer, they can take various actions, such as viewing contents, page turning, page jumping, bookmarking, highlighting, adding logs, taking memos, looking words up in the Web dictionary, and searching by keywords. These actions of learners are recorded to AETEL database as action logs (Fig. 2(3)). MyLearning is a seamless learning function which enables learners to connect eBook learning with a real-life learning (Fig. 2(4)). AETEL users can use SCROLL original functions as mentioned above such as add logs, view logs, and relog them in SCROLL as well (Fig. 2(5)). Details are described in Kiyota et al. (2016).

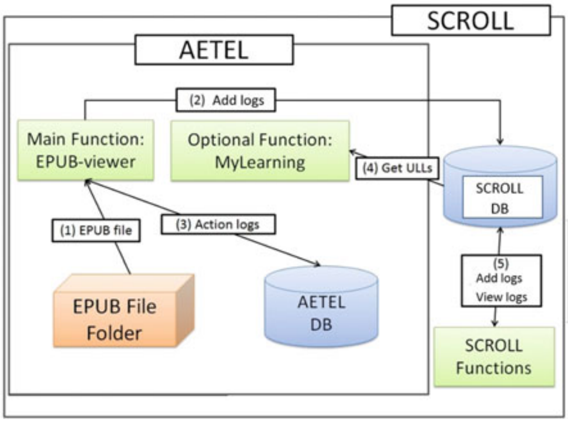

Fig. 2 AETEL architecture

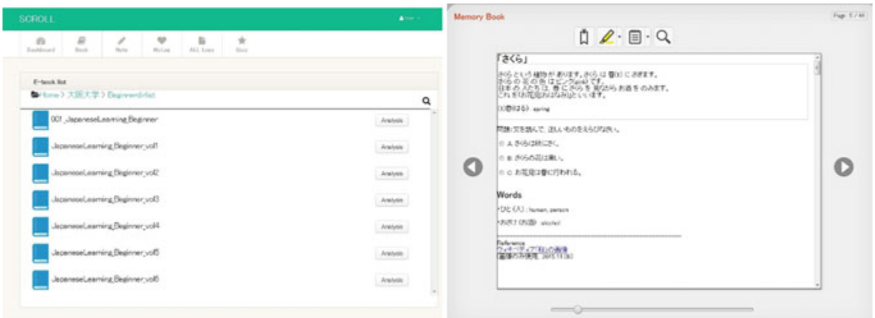

Fig. 3 EPUB File Folder (left) and EPUB-viewer (right)

3.3 VASCORLL

The aim of VASCORLL is to support learners to apply what they have learned through eBook (AETEL) to their daily life experiences and vice versa. To bridge both eBook learning and real-life learning, this study designed innovative visualization structures as shown in Fig. 4: eBook learning structure (ELS) and real-life learning structure (RLS). ELS consists of three layers, which are called “eBook learners,” “words learned through eBook,” and “learning materials.”

(1) eBook learners: The upper layer shows learners studying in e-book learning.
(2) Words learned through eBook: The intermediate layer shows words that they have learned using eBook viewer interface.
(3) Learning materials: The lowest layer shows learning materials uploaded by teachers.

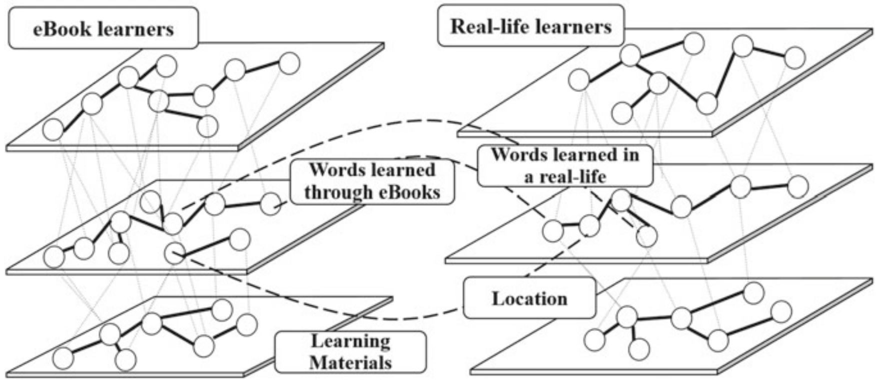

Fig. 4 Visualization structures in the seamless learning environments: eBook learning structure (ELS) and real-life learning structure (RLS)

To visualize the relationships among eBook learners, words learned through eBook and learning materials, this paper visualizes the relationships based on network directed graph. How does our visualization method connect each node? For example, if a learner learns and saves a newly learned word using eBook viewer interface, our visualization method will connect the learner' node in the upper layer in the ELS to the word' node in the intermediate layer in ELS. Moreover, the word' node will connect to the learning material nodes in the lowest layer in ELS. By visualizing these links, teachers and students can grasp which eBook learning contents have the target word.

RLS includes three layers, which are called "real-life learners," "informal words," and "locations."

(1) Real-life learners: The upper layer shows learners studying in an informal setting such as museums, restaurants, and city halls using SCROLL.
(2) Words learned in a real life: The intermediate layer shows words that they have learned in a real-life setting using SCROLL.
(3) Locations: The lowest layer shows contextual data such as location and place where they have learned in a real-life setting using SCROLL.

For example, if an international student learns a word "natto (納豆)" (a traditional Japanese food made from soybeans fermented with Bacillus subtilis) by an eBook, there might be a lot of opportunities to learn "natto" in various places such as supermarkets, shopping malls, and restaurants in a real life.

However, it is difficult for him/her to know where it can be learned. In addition, it is difficult for learners to find which words were frequently learned by learners in a variety of learning environments. These words could play an important role to bridge over eBook and real-life learning to realize the seamless learning environment.

We hypothesize that the betweenness centrality is the most effective in bridging eBook learning over real-life learning. By using betweenness centrality, it is expected to find most important words to bridge over ELS and RLS side. The most important word means the most frequently uploaded words in both eBook learning and real-life learning. Our hypothesis is based on the fact that betweenness centrality represents the degree of which nodes stand between each other. A node with a high betweenness centrality has more control over the network. Therefore by using betweenness centrality, it is expected that the most important words (words with a high betweenness centrality) could bridge over ELS and RLS side.

Mouri and Ogata (2015) proposed Ubiquitous Learning Graph (ULG) which was divided into four areas: words (top-left), learners (bottom-left), locations (top-right), and time (bottom-right). They reported that it was important to consider readability and ease-of-use of the nodes' positions on the network graph when visualizing the relationships in the real-world language learning. Considering these points, we have developed a network layout called "seamless learning graph" (SLG), which is divided into six areas as shown in Fig. 5(top): eBook learners (upper-left), words learned through eBooks (center-left), learning materials (bottom-left), real-life learners (upper-right), words learned in a real life (center-right), and locations (bottom-right). These areas represent the layers as shown in Fig. 4.

4 Empirical Study with VASCORLL

In this section, one real classroom implementation of VASCORLL is introduced. The evaluation was conducted under the full-seamless condition to examine if VASCORLL contributes to more effective vocabulary learning than the conventional method. Detailed description can be found in Mouri, Ogata, and Uosaki (2017).

4.1 Method

The study group consisted of 20 international students studying in Japan, who were divided into two groups (test group and control group) with equal keenness in language learning according to the number of their uploaded logs to SCROLL during the practice session (first week in Fig. 6). Group A consisted of five Chinese, four Mongolians, and one Malaysian. Group B consisted of three Chinese, five Mongolians, and two Thais. The evaluation lasted from May 22 to June 11, 2015.

The students were aged from 21 to 36 years old. Their length of stay in Japan ranged from 1 month to 5 years. The evaluation experiment was designed to evaluate the following three criteria:

- Whether VASCORLL can increase the participants' learning opportunities ("learning opportunities" denote that the number of logs uploaded by the learners to the system during the evaluation period").

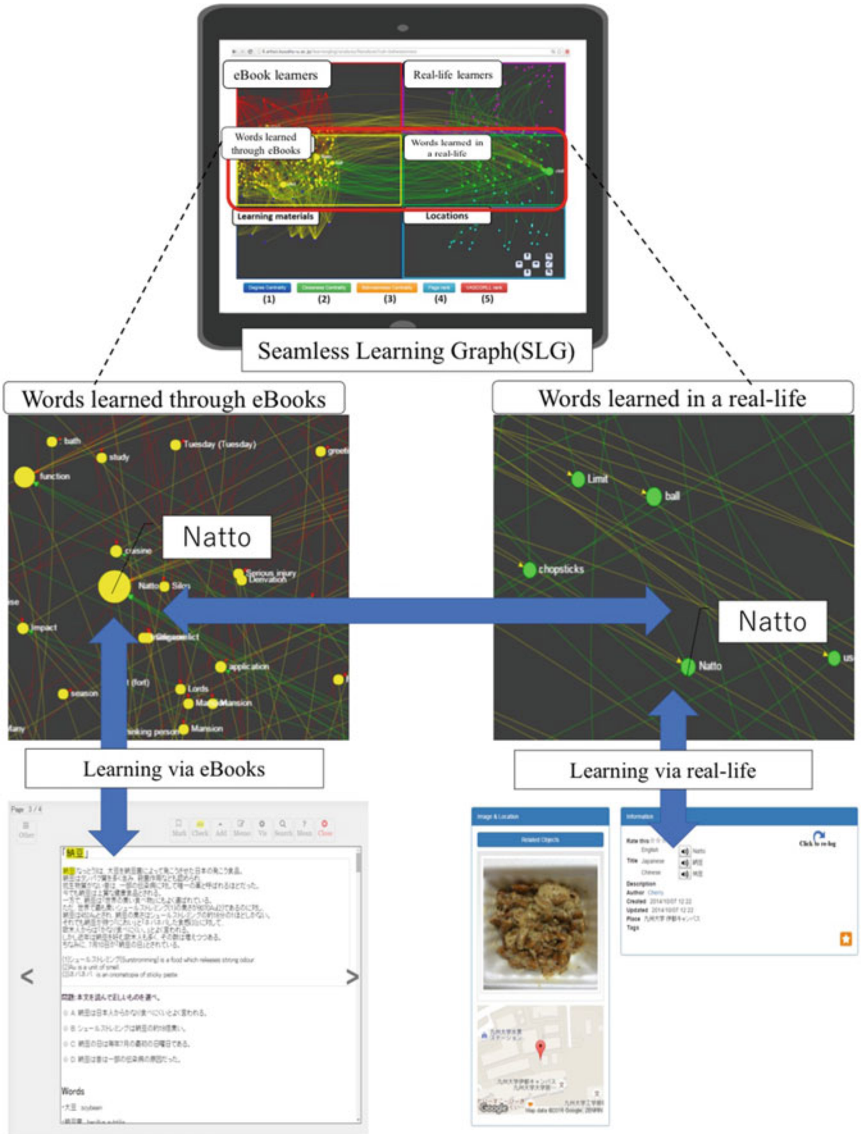

Fig. 5 VASCORLL interface and learning process

- Whether VASCORLL would be benefit in terms of usability in finding important words in the seamless learning environment.
- Which centrality is effective in supporting learning in the seamless learning environment?

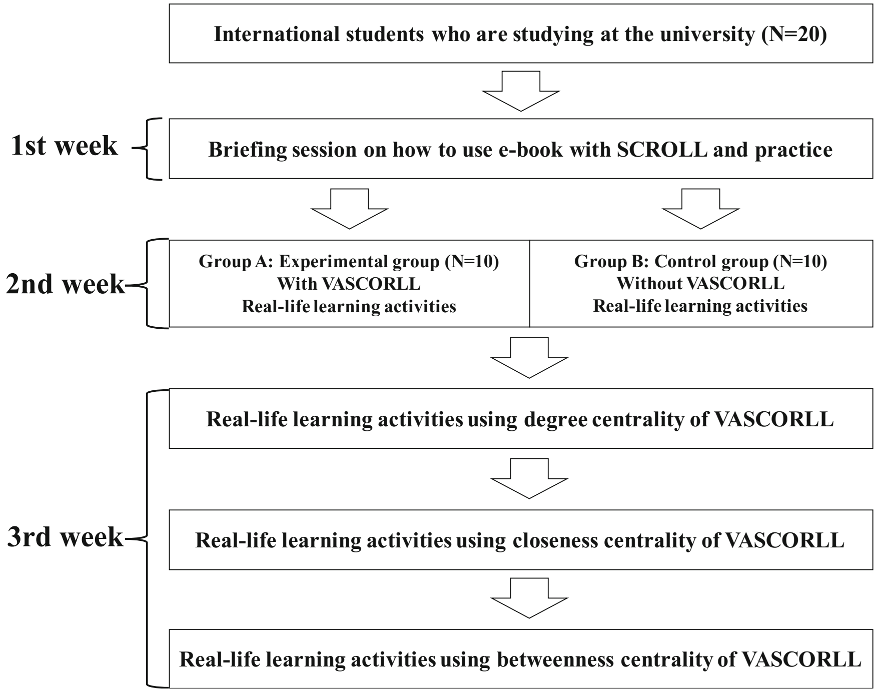

Fig. 6 Procedure of the evaluation

Before the evaluation period, a Japanese language teacher uploaded eBook learning contents to the server. The contents were categorized according to the Japanese language proficiency level.

First Week

At the beginning of the first week, the participants had a briefing session on how to use eBook system with SCROLL since it was their first time to use it. They used the eBook system with SCROLL for one week to get used to it before the introduction of VASCORLL. Based on the number of the uploaded logs to the system during the first week, they were divided into two groups to make the two groups as even as possible in terms of the keenness of language learning: Group A (experimental group) and Group B (control group).

Second Week

VASCORLL was introduced to Group A. Both Group A and B were instructed to upload newly learned words through both eBook and real-life experience to SCROLL. As for Group A, they were instructed to search them by the search window to visit VASCORLL page as in Fig. 5 and find related words. If they thought they were useful, they were instructed to relog them to be their own logs. They were instructed to do this task either right after they upload their new words or at the end of the day for reviewing.

Table 2 Number of logs uploaded and relogged during the first week (practice period)

Group	Number of participants	Number of uploaded logs	Mean	SD	*T*	*P*
Group A	10	143	14.3	6.78	0.201	$P > 0.05$
Group B	10	149	14.9	6.51		

Third Week

Both groups were instructed to go to VASCORLL pages, try three types of social network analysis as much as possible to find out which centrality was the most helpful to find the central/important words in the graph: the degree centrality for the first two days, the closeness centrality for the second two days, and betweenness centrality for two days.

Table 2 shows the total number of the logs uploaded and relogged by the participants during the first week. Group A participants uploaded and relogged 143 logs totally, while Group B participants uploaded and relogged 149 logs to the system. Since the two groups were created to be equal in terms of the keenness of language learning based on the number of logs, there was no statistically significant difference between them ($t = 0.201$, $p > 0.05$). Then, at the beginning of the second week, the instructors introduced VASCORLL.

Group A learned words in their daily lives and words in the eBook contents using the AETEL with SCROLL and VASCORLL. Group B learned words in their daily lives and words in the eBook contents without VASCORLL. The participants used their own smartphones to upload their newly learned words in both eBook learning setting and a real-life setting. The mobile devices used in the evaluation experiment were three iPhone 4s, fourteen iPhone 5s, and three Samsung Galaxy Note 3s.

During the third week, both Groups A and B participants evaluated each centrality based on social network analysis during real-life learning activities. They learned words recommended by the system based on the three algorithms: degree, closeness, and betweenness. They were asked to use the prearranged one centrality. After the evaluation experiment, the participants were asked to complete five-point scale questionnaires to evaluate the system performance and usability, as well as the user-friendliness of understanding the contents and finding logs using each centrality in VASCORLL.

4.2 Results and Discussion

To examine whether the participants' learning opportunities were increased by our proposed VASCORLL, we compared the number of the uploaded logs of Group A with that of Group B using *t*-test. Table 3 shows the number of logs uploaded/relogged by the participants during the second week. Group A uploaded 189 logs, and Group

Table 3 Number of logs uploaded and relogged during the second week

Group	Number of participants	Number of ULLs	Mean	SD	t	P
Group A	10	189	18.9	6.41	2.11	$P<0.05$
Group B	10	127	12.7	6.75		

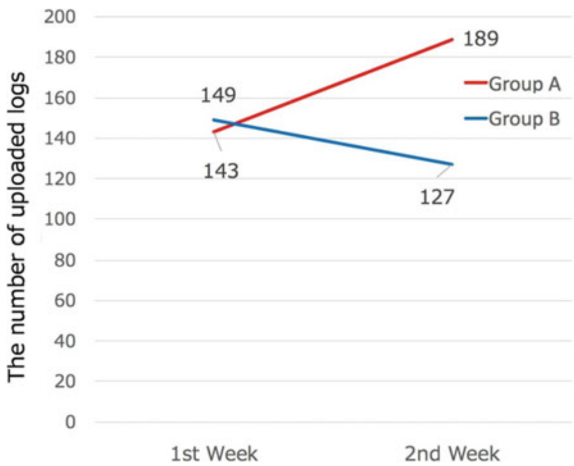

Fig. 7 Comparison between the number of logs uploaded and relogged during the first and the second week

B uploaded 127 logs to the system. The mean and the standard deviations were 18.9 and 6.41 for Group A, and 12.7 and 6.75 for Group B. The number of the uploaded/relogged logs was significantly different with $t=2.11$ ($P<0.05$), implying that VASCORLL was able to increase the number of the uploaded logs. Figure 7 shows the comparison between the number of the uploaded logs during the first week and the second week. The number of uploaded logs of Group A increased by the rate of 130%, while that of Group B decreased by the rate of 85%. It implies that VASCORLL plays an important role to increase the number and that it can be a useful tool to increase the learners' learning opportunities.

Table 4 shows the results of the five-point scale questionnaires (Best: 5, Worst: 1). Q1 asks whether the participants were able to find that the words they learned through eBooks were connected to the words that other learners learned in a real-life learning setting. Similarly, Q2 asks whether they were able to find that the words they have learned out of classes were connected to the words that others have learned through eBooks. The results of Questions 1 and 2 revealed that the participants found the words they learned though eBooks were connected to the words learned in a real life and vice versa. For example, some participants learned the Japanese word "natto (納豆)" through eBooks. By uploading "natto (納豆)" to the system, the system showed them that other participants have learned it at the shopping mall and supermarkets. In this manner, VASCORLL was able to connect one identical word learned through eBooks and learned in a real-life learning. Q3 asks whether the participants

Table 4 Result of the five-point scale questionnaires for evaluating the usability of the system (Group A)

Question	Mean	SD
Q1. By using VASCORLL, were you able to connect words learned through eBooks to those learned in a real-life?	3.7	0.82
Q2. By using VASCORLL, were you able to connect words learned in a real life to the words learned through eBooks by other learners?	3.9	0.99
Q3. By using VASCORLL, were you able to find that the word you learned was connected to the places where other learners learned the same word?	3.4	0.96
Q4. By using VASCORLL, were you able to find your newly learned words were used in other eBook contents?	3.5	0.87
Q5. Was VASCORLL easy to use?	2.6	1.23

were able to find that their newly learned word was connected to the places where other learners learned the identical word by using VASCORLL. For example, when a participant learned the Japanese word, "ryouri (料理) (cuisine)" in eBooks, he/she could find that it was connected to the experiences of others at places such as schools and restaurants. By sharing the real-life experiences, VASCORLL enabled them to experience indirectly what other people experienced, which means, we believe that the system connected their eBook learning to their indirect real-life learning to produce a seamless learning environment. Q4 asks whether the participants were able to find their newly learned words in other eBook contents. For example, when a participant learned "shiyou (使用) (use)" through AETEL content titled "Japanese Learning Beginner Vol. 1", the system connected it to other AETEL contents such as "Japanese Learning Beginner Vol. 2" and "Onomatopoeia Japanese Learning Vol. 1". In this manner, they could learn that it was a frequently used word in the Japanese. Q5 asks whether VASCORLL was easy to use.

During the third week, both Groups A and B participants evaluated each cent. They were also asked to evaluate the usability in terms of operability and readability of the visualized graph. The response shows that many participants felt that VASCORLL was not easy to use. They were asked to give comments regarding this problem, and the negative comments were as follows:

(1) The speed of visualizing and analyzing logs in the system is too slow (about 20–30 s).
(2) If visualizing logs using a mobile device, it is hard to read the nodes because of very small screen size. However, if logs are visualized on a personal computer, they become very easy to read.
(3) It was a little bit difficult to understand how to use the system.

The comments 1 and 2 suggest that the system developers need to improve the functionality in accordance with their mobile device and system' speed in visualizing

Table 5 Result of the five-point scale questionnaire for evaluating each algorithm ($N = 20$)

Question	Mean	SD
Q1. Was the degree centrality easy to find central words in the network graph?	3.0	0.91
Q2. Was the closeness centrality easy to find central words in the network graph?	2.7	1.08
Q3. Was the betweenness centrality easy to find central words in the network graph?	3.7	0.86

a large number of logs. Comment 3 shows that even though they had a briefing session on how to use VASCORLL prior to the evaluation experiment, there were some participants who did not understand fully how to use it. Thus, in our next evaluation, more careful attention would be paid on whether they understand it fully.

Table 5 shows the result of the five-point scale questionnaire for evaluating each centrality (degree, closeness, betweenness). Q1–Q3 asked whether the participants were able to find central words using the fundamental social network analysis: degree centrality, closeness centrality, and betweenness centrality. From the results of the questionnaire, most participants preferred betweenness centrality since the mean score of the Q3 is the highest.

To find the most effective centrality to learn central words, we interviewed the participants to compare betweenness centrality with other centralities.

(1) Degree centrality versus Betweenness centrality
Degree centrality enabled the participants to find merely nodes that have many links. Two participants selected the centrality in terms of usability and effectiveness for learning because it is simple and easy to understand the characteristics as shown in Fig. 7. However, most participants commented that it was difficult to find words bridging eBook learning over real-time learning because the size of eBook and real-life learner nodes became larger than those of words.

(2) Closeness centrality versus Betweenness centrality
When comparing closeness centrality with the betweenness centrality, the closeness centrality was not useful to find central words in the seamless learning environment. There was no numerical value difference between words learned through eBooks and those learned in a real life, so that the participants could not find the central words. Therefore, this paper concluded that the closeness centrality was not a useful centrality in finding central words in the seamless learning environment using our visualization and analysis method.

As shown in Fig. 8, the majority of the participants preferred betweenness centrality to other centralities. We asked them why they preferred the betweenness centrality than the other centralities. Their feedbacks were as follows:

- The betweenness centrality was very good because it was easy to find words in my eBook contents linking to words in a real life.

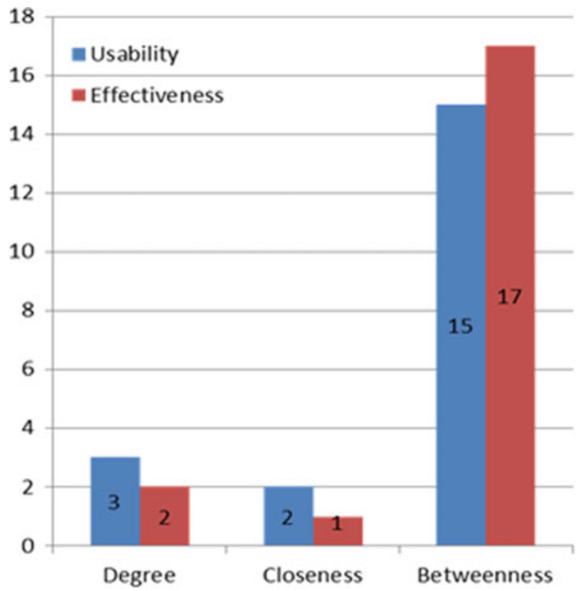

Fig. 8 Number of selected centrality by each participant

- It was easy to understand. And I learned some words. Then, it recommended some useful words to me (e.g., the different sizes of the nodes (large and small) and color coding such as green or yellow nodes were easy to recognize).

Therefore, the betweenness centrality was the best centrality of all in terms of easiness to find words bridging eBook and real-life learning. Comparing the betweenness centrality with other centralities, fifteen participants answered that the betweenness centrality was helpful in finding central words. Seventeen participants answered that it worked effectively in language learning.

5 Conclusions and Future Work

This paper described a system called VASCORLL for visualizing and analyzing learning logs collected in the seamless language learning environment in order to bridge over eBook and real-life learning. VASCORLL works on physical setting to link learners in the real world with learning logs that are accumulated in the cyberspaces using AETEL with the ubiquitous learning system called SCROLL. AETEL with SCROLL enabled the learners to learn through two learning activities: an eBook learning activity and a real-life learning activity.

The visualization and analysis methods were based on graph theory, social network analysis, and graph drawing algorithms in order to find pivotal words in the seamless learning environment. The three layer structures called ELS and RLS were adapted as the visualization methods. In this manner, teachers and students could easily grasp words bridging between words in ELS and RLS. In addition, this paper evaluated whether they were able to find the most pivotal words on the network graph using each centrality based on social network analysis.

In the evaluation of the system, since the number of the subjects was small, there was no statistically significant difference. However, the result of the second week phase evaluation showed the clear difference of the two groups in terms of the number of logs uploaded/relogged (cf. Table 3 and Fig. 7). The results of the questionnaires on VASCORLL showed that VASCORLL was a useful tool in finding the central words linking eBook learning to real-life learning. The result of questionnaires on the three types of centralities showed that the most effective one for learning was betweenness centrality. Therefore, we concluded that the betweenness centrality is the most effective centrality in the seamless learning environment.

VASCORLL will be evaluated repeatedly in the future, with the improved processing speed of visualizing and analyzing learning logs improved. In addition, our future work includes applying VASCORLL to other application domains such as math, physics, and science education, and long-term evaluations with a sufficient number of participants.

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Chapter 10
Seamless Writing: How the Digitisation of Writing Transforms Thinking, Communication, and Student Learning

Otto Kruse and Christian Rapp

1 Introduction

Writing is one of the most common learning activities in secondary, higher, and further education. The distinction between *learning to write* and *writing to learn*, as introduced by Emig (1971), suggests that there are two interrelated modes of learning. Most kinds of student writing are part of the student's learning assignments (writing to learn) which are used to involve students in some kind of disciplinary learning. However, if students are taught explicitly how to write, then it is considered as *learning to write*. Each writing-to-learn assignment also involves students' learning to understand the rules, conventions, strategies and textual genres, meaning that both modes of writing/learning are usually interconnected.

Even if writing is seen as a singular competence of its own, it is not a uniform activity but differs markedly between disciplines and their diverging epistemologies as contrastive studies have shown (Langer & Appelbee, 1987; Poe, Lerner, & Craig, 2010; Walvoord & McCarthy, 1990). In higher education, writing assignments are highly heterogeneous. Nesi and Gardner (2012) found over one-hundred genres in use for writing assignments at British universities and demonstrated that each genre is connected to a different learning task that fulfils students' knowledge-based

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functions. Each task requires different skills and is connected to different procedures. Students soon learn that writing differs from task to task, from discipline to discipline, and even from instructor to instructor.

The digital revolution has changed writing and the teaching of writing in several fundamental ways, bringing an end to the technologies first introduced by Gutenberg in the fifteenth century. Even though writing has always been integral to the 'technologising of the word' (Ong, 1982/2002), the digital age has accelerated that pace of change and has led to several subsequent generations of new writing technologies. Assessing the impact of digital change on writing and writers is difficult; however, as the crucial activities in writing are mental by nature, they, are therefore, not directly visible. Seams in writing are not only contextual or social in nature, but also cognitive or mental, thus, related as much to intellectual challenge than to the organisation of learning.

Seamless learning is a concept reaching back to the pre-digital age with a first definition from Kuh (1996) referring to the untying of learning from such restrictions as the campus situation, curriculum, or the academic content of assignments. A second conceptualisation was tied more closely to digital learning, and in particular to the availability of mobile devices, which seem to offer completely new teaching and learning opportunities. Chan (2015) suggested that seamlessness 'has become an overall concept in describing what technological innovation and impact may bring to education' (p. xiii). This rather broad use of the term refers to the new opportunities that digital learning, including the widespread availability of connected mobile devices, has brought to teaching and the new ways of learning it has introduced. It is, however, an optimistic, constrained view of such technological changes, lacking a sceptical or critical perspective on digitisation. Problems of technology adoption and acceptance (for a discussion on new learning technologies in higher education, see Gülbahar, Rapp, Kilis, & Sitnikova, 2017; and for writing technologies, see Rapp & Kauf, 2018), resistance to innovation, cognitive impoverishment, new reading problems, etc. are outside of the analytic scope of this concept. There seems only one developmental direction in the seamless learning concept running from more to less seams, or their bridging, and from lower to higher seamlessness.

Since the initial definition of seamless learning by Kuh (1996), many definitions of what was known as mobile seamless learning (MSL) [Chan et al. (2006), and a 2015 reflection upon his initial work; the synthesis of Wong and Looi (2011); and its subsequent refinement by Wong (2012); and an extensive and thorough account of the genesis of the field and its definitions by Wong (2015)] have still not brought about a conclusive definition of the term seam. Furthermore, Wong (2012) asserts that '…seamless learning remains to be a loosely posited learning approach and yet-to-be established learning model' (p. E19). From an analytical perspective, prior to theorising, it should be understood that seam refers to a very broad category of phenomena such as obstacles, frictions, barriers, breaks, gaps, imbalances, disparities, inconsistencies, or discontinuities. It seems fair to assume that seams are unfavourable for learners while seamless learning arrangements, which consequently would be barrier-free, integral, homogeneous, balanced, consistent, or continuous in time (lifelong learning) and space (referring to the different context within which learning takes place) would be more favourable for learning. However, Sharples (2015), who connects seamless learning to Csikszentmihalyi's (1990) flow experience, challenges this assumption when he says: 'There is no evidence that providing a continual flow of learning materials will result in effective learning, and the learner should not just stop and start the flow of learning but control and guide it' (p. 44). On the other hand, it is an unexplored question as to what extent experiencing seams can provide valuable or even necessary learning opportunities leading to a deeper understanding of subjects or problems. Seamlessness (in the sense of a flow-experience) obviously does not in itself guarantee useful learning, and it appears wise to use seamlessness as a descriptive category in helping us to understand changes in learning contexts but not as a concept that directs us automatically to more powerful, effective and personally profitable kinds of learning.

One should be aware that bridging or removing seams from one place may just result in the creation of new seams someplace else. Thus, it could be said that there are more favourable or less favourable seams and that it may be justified to remove certain seams while creating others. There will never be a context without seams and any form of teaching first has to *produce* seams; for instance, when teaching students to think as members of their discipline, barriers have to be created to the thinking modes of other disciplines. Similarly, the development of stable learning habits means to create, or become aware of seams such as finding out when to learn, when to relax, when to study individually, when to collaborate, when to socialise, when to play, and when to work. Seamless learning makes teaching more flexible and may better connect it to its context or consider respective affordances but will never make it seamless in the literal sense.

Looking closer at how seamless learning is referred to in the literature, the most important referential point still seems to be the 10-point list of mobile seamless learning (MSL) dimensions by Wong and Looi (2011), defining the spaces where seams may be removed or reduced:

(1) Encompassing formal and informal learning
(2) Encompassing personal and social learning
(3) Across time
(4) Across locations
(5) Ubiquitous access to learning resources
(6) Encompassing physical and digital worlds
(7) Combined use of multiple device types (technology)
(8) Seamless switching between multiple learning tasks
(9) Knowledge synthesis (prior knowledge, new knowledge, multidisciplinary learning)
(10) Encompassing multiple pedagogical or learning-activity models (facilitated by teachers)

The list shows where seams in traditional learning may be expected, and where there are borders or barriers that may be transgressed when introducing new learning technologies. If this list were to be applied to the field of writing, only some of the seams may be touched, whereas others may be of lesser relevance. Writing always encompasses formal and informal learning (dimension 1), but it is less the technology that decides this, rather it is the genre and/or situation in which students are asked to write. Personal and social learning (dimension 2), in contrast, may well be influenced by new technologies, as is the case when using forums, learning platforms, document sharing software, chat rooms, text messages, etc., where formal and personal modes of writing may be combined in new ways as compared to writing on paper. The time and location (dimensions 3 and 4) where writing takes place may also be influenced by new technologies, but all the way back to the invention of paper and the pen, reading and writing have been ubiquitous and practised virtually anywhere. A closer look, therefore, has to be taken at which aspects of writing have actually changed with respect to time and space. Ubiquitous access to learning resources (dimension 5) certainly is a key change in digital writing, opening new ways of reading, referencing, communicating, and collaborating. Encompassing physical and digital worlds (dimension 6) is a seam that seems to be created by the new technologies and seems to deepen the more technology we use. Writing has always encompassed the use of several devices (dimension 7), with writing media such as the pen, paper, typewriters, and the former schoolroom classic, the blackboard and chalk, which was followed by the (non-interactive/smart) whiteboard. Similarly (dimension 8), pre-digital writing always allowed for switching between tasks (writing letters, notes, lists, essays, etc.). Finally, writing always functioned as a means of knowledge synthesis (dimension 9) and has been used in many different pedagogical situations as a means of learning (dimension 10), not just one.

Wong and Looi's (2011) list seems to have been generated with classroom teaching at schools in mind, aiming to overcome rather traditional teacher-centred school settings, but not with respect to a fluid learning technology such as writing. It certainly addresses relevant seams for changes in classroom situations but needs to be extended when used to analyse writing technology.

In this chapter, the terms seam and seamless are used in a descriptive way to refer to obstacles and barriers in learning/writing processes or experiences. The concept helps to detect structural problems hidden in the contextual learning arrangements of writers and find pedagogical solutions to situations where new technologies are introduced. As an example, where seams in writing have changed, the successive stages of technological innovation are looked at first before going on to describe *Thesis Writer*, a self-developed learning platform picturing the opportunities that new technologies offer in rearranging the traditional learning field of thesis writing.

2 Seams and the Development of Digital Writing Technology

Writing has been ubiquitous and its tools mobile long before the digital revolution started. For several centuries, paper, notebooks, pencils, books, and brochures allowed for writing and reading anywhere and at any time. This revolution of literacy started with the invention of the printing press, along with some later innovations in writing technology such as the iron pen, lasting ink, low-cost paper, and new printing formats such as brochures, magazines, periodicals, and paperback books. The first generation of digital tools, in contrast, immobilised writing by tying it to voluminous desktop computers and heavy printers and thereby made it dependent on the availability of computer hardware at schools and universities. The real revolution of writing was not in the tools' reduction in physical size or in their added mobility. Word processors and, later, the introduction of the Internet and email were the technological innovations to effect writing sustainably. These two innovations tore down the traditionally dominant seams in the field of writing far more than the effect of the physical tools' miniaturisation or mobility. Additionally, it seems that mobility per se is of no great significance to writers. Neither the smartphone nor the tablet offers comfortable, realistic writing programmes that reach beyond the writing of relatively short text messages. They are more suited to brief text, emoticons, and picture-based or postcard-like exchanges, but not for the production of significant voluminous text.

To understand seamless writing, changes have to be looked for in places other than the mobile attributes of the tools. Digital writing technologies and their integration into the writers' routines have evolved in several steps and successively replaced the older technologies of hand and machine writing, copying, the printing press and communication employing traditional postal services. New technologies have obscured the borders between writing, text design, communicating, storage, mailing, and publishing in order to arrive at solutions that make all of them manageable within a single system, the personal computer, laptop, or notebook. These innovations have happened successively since the 1980s, and each will be introduced step by step in the following sections.

2.1 Personal Computers and Word Processors: The Big Bang of Digital Writing

The introduction of the personal computer and—connected to it—writing programs such as Corel's WordPerfect which was followed shortly after by Microsoft Word, were the first major step into the digital age of writing (see Mahlow & Dale, 2014, for a thorough account). The first digital typewriters can be ignored in this evolution as they were only a transitional technology with a limited range of digital features. These new writing programs from the early 1980s were commonly called word processors or text editors and offered writers something that was fundamentally new: the complete replaceability of any written word without need for erasers or mechanical replacement tools. Any word could be immediately, or at any time later, deleted and/or replaced by another. Letters, words, and sentences could be removed in part or in whole from their original placement and shifted elsewhere in the text. Writers became able to work on any part of their paper and jump to any place within the text at will. The use of draft hardcopy versions became dispensable as text could be developed continuously. New opportunities to organise and structure text were provided by the outline function. Formerly, complicated matters such as footnotes and registers could be created automatically. Grammar, syllable division, and spelling functions allowed for automated or semi-automated text correction without need to refer to a book on grammar or even a dictionary, both of which were soon integrated into these new writing systems.

This first step in the digitisation of writing was by far the greatest and most fundamental which laid the ground for everything that followed. Many seams were removed, which could be referred to as 'media seams' which formerly restricted the writer's activity by the boundaries of symbol notation systems based on the physical painting or imprinting of letters onto the surface of paper (or any other non-interactive media). Removing these seams led to new ways of organising the writing process and new habits of connecting writing with thinking. The opportunity for a fluid arrangement of words on media led to a more elegant way of thinking by creating thoughts and evaluating their impact on the emerging text. Digital media freed the writing process from technical restrictions, connecting revision activities with rewriting the whole text and added new opportunities for idea generation, idea organisation, and idea import from other sources. Sharples and Pemberton (1990, p. 2) labelled the new technological opportunities of digital writing as 'externalising cognition' and explained this idea as, 'In the place of a sheet of immovable text, the computer can provide a dynamic medium for exploring ideas and plans'. The now effortless changeability of the written word with the introduction of the word processor was the great technological breakthrough into digital writing. Technological changes that followed such as increased multimodality, the graphical designability of text, its exchangeability and reproducibility through web-based media, mobile telephony-related technology, new publishing opportunities, collaborative functions, and newly created automated feedback and intelligent tutoring systems built on this fundamental innovation.

2.2 Computer Laboratories: New Writing Opportunities, yet an Immobile Technology

The expensive new computer technology entered education through the introduction of computer laboratories which, at the beginning, were the only access to computers most students had, even though families soon started to buy one of the new PCs and thereby children may have had limited computer access at home. For writing, it was essential that the computer laboratories were connected to printers, which at the beginning were even more expensive than the computers themselves. Computer laboratories, of course, produced new seams, restricting writing to a certain space and often also to a certain time schedule. Switching between handwriting when taking notes in lectures or from books in libraries still was a common seam as was the restricted access to digital communication means. All writings had to be printed out and carried to the readers or be transmitted by discs (sent by physical postal mail). In spite of these restrictions, computer laboratories were an important means to acquire digital literacy and to acquaint students with the basic MS-DOS commands of the dominant system software of the time.

2.3 Internet and E-Mail: Removing the Seam Between Writing and Communication

Although developed separately, the Internet and email had similar effects on writing as both offered comfortable new ways of sharing texts with writers from anywhere around the world. The seam between writing and communication suddenly disappeared and sending a letter, now called email, was reduced to handling a fairly simple program and the pressing of a single button. One of the greatest seams of writing, and the exchange of texts, had been the postal system by which a paper had to be placed in an envelope and transported by mail carriers to another person or institution. Writing and communicating became manageable through a single system without writers and/or readers even having to leave their computer screen.

When the World Wide Web (www) was created, importing texts from sources or other writers became equally easy and the distribution of texts became independent of libraries, postal offices, and physical books. A simple 'www' address was adequate to access a particular text and then download it to an individual computer display screen. However, the reverse process of placing text onto one of the many websites (and thus making it visible to all) was not so easy. Uploading text onto the web, without knowledge of Hypertext Markup Language (HTML), required the invention of content management systems providing WYSIWYG ('what you see is what you get') editors to be used as easily as the word processor. The web reduced one of the greatest seams in writing, that between individually written text and published text. The web also provided the technological basis for the principal permeability of textual content between documents existing in different parts of the world on one of many servers connected through the Internet. Copy and paste became a common form of writing, even where it clashed with well-established rules of plagiarism and the ethics of writing. Search engines and online lexica provided easy access to all kinds of knowledge, and increasingly more knowledge became available in digital form. This revolution of knowledge distribution, again, reduced another seam, which traditionally separated the individual and the required knowledge which until then was in the form of physical books and papers, and knowledgeable groups of insiders.

New seams, however, emerged from the internal organisation of the web, making it difficult to assess the quality of the information provided and the intentions of the providers. While the boundaries excluding users from relevant knowledge were certainly reduced, new seams began to evolve between the various types of Internet content, thereby making it difficult to distinguish the quality of knowledge. Commercialised informational offerings and political propaganda were seemingly equal to trustworthy information. Learning to make the distinctions between different qualities became a new task for readers.

2.4 Learning Platforms: Starting the Age of Virtual Teaching and Blended Learning

The creation of local networks interconnecting individual PCs was soon surpassed by the Internet offering a new powerful means for the organisation of learning processes and for communication within wider learning communities. The invention of learning platforms complemented the person-to-person meetings in teaching with virtual meeting places that allowed for the exchanging of texts within selected groups of students and their instructor(s). Communication and instruction regarding organisational issues could now be accomplished through the learning platform. Instead of depositing books and papers in the library, materials can now be scanned and provided electronically. The seam between the symbolic sphere of teaching (i.e. the texts, ideas, and theories) on the one hand, and the physical sphere (i.e. the persons gathering in meetings) on the other was dissolving. Reading, talking, communicating and self-presentation became now part of one inclusive virtual environment. The age of virtual teaching and blended learning had begun. It also had established a completely new seam: that between the real and the virtual world.

2.5 Social Media: Community Building the Digital Way

The rise of social media and their new forms of social interaction, self-presentation, and digital interaction through such means as postings, likes, emoticons, texts, and comments started its rise at educational institutions such as Facebook at Harvard University, but which soon expanded to become universally available. Given the popularity of social media among the younger generation, the question arose as to whether or not, and to what extent social media can be usefully applied to teaching and learning in schools (Richardson, 2010) and in higher education (Gülbahar et al., 2017). The accessibility of social media through laptop computers and mobile telephony devices such as tablets and smartphones has ultimately made social media ubiquitously accessible. Social media, however, did not significantly promote the art of writing, but rather fosters the expressive opportunities of multimedia making it easier to communicate personal content.

2.6 Laptop, Tablet, Smartphone et al.: Learning Becomes Mobile

Mobile learning (Berge & Muilenburg, 2013) became one of the great trends of the 2000s and inspired educational technology and pedagogy to reach beyond traditional classroom teaching and make learning universal, more communicative and able to bridge between formal and informal learning (Wong, 2015).

Connecting seamless learning with the transgression of contextual borders (or even the disappearance of contexts) and tying the nature of student learning to the availability of their own technological device(s) (through 1:1 availability), certainly pictures a kind of learning that moves well beyond the physical constraints of the classroom. Most writing, however, is undertaken outside of the classroom, as homework assignments from school, or as a seminar paper, essay or a thesis written as part of a university education. Mobility and 1:1 availability of mobile devices has not brought about much change for these writing practices. Students now write text on their laptop computers at home and carry then them back and forth to school, much in a similar way to how they formerly carried their paper-based notebooks or, later, floppy discs. The main cognitive activities did not change because of the mobile devices but rather due to the new writing software and the exchanges through the Internet and email.

The optimism towards more 'continuity of the learning experience across different scenarios or contexts' as Chan et al. (2006, p. 6) expressed, may apply to school teaching but seems less justified when it comes to writing projects at university level which usually rely more on source reading, thinking and meaning making than on small-scale learning assignments. Still, the meaning that mobile devices in general have for university learning is an issue that to be discussed separately.

2.7 Document Sharing and Collaborative Writing: One Text, Many Writers

New technologies massively impacted on the opportunities for collaborative and cooperative writing. Already, the invention of social media enhanced opportunities to cooperate on text production and share texts in a way that the paper age did not allow. There was, however, another invention that brought writers together in a new way to collaboratively write text. The invention of document-sharing and (real-time) collaborative writing-tools such as Etherpad, Google Docs, Zoho Writer, and

MixedInk brought about new potential for cooperation and distance writing that may have received less attention than other innovations but nonetheless, greatly impacted on writing. What had been a brazen limitation of writing—that only one person was able to write on a text at the same time—has fallen quietly behind with this new technology. Now, two persons or even larger groups can write the same text from many different locations and, additionally, collaborate through comments they may add or within chatrooms. The text, initially an individual product, which had become a social unit when placed on the Internet, now turned into a collective product. The disappearance of this seam enables collaborative text production without such traditional limitations as individual skills, ownership and responsibility. Collective text production merges the influence of several writers into one shared product. Even if the individual contributions to the text may be visible during the writing process (marked by different colours, for instance), the end product blurs all boundaries between the individual contributions.

2.8 Automated Feedback, Intelligent Tutoring, and Digital Scaffolding: Reconnecting Writing and Instruction

New opportunities of cloud computing in connection with substantial pedagogical, linguistic and computer-linguistic research have led to a new generation of support measures providing writers with individualised instruction, guidance, and feedback (for an overview see Allen, Jacovina, & McNamara, 2015; Cotos, 2015). Many of these tools offer word processing for text production and connect it with additional instructive, evaluative and supportive measures. Here, the seams that traditionally separated writing from the teaching of writing are fading away. Writing to learn and learning to write merge indistinguishably: While students are writing on their assignments, they can draw upon a large variety of support functions, responsively providing them with the type of advice needed and offering the opportunity to learn something new about writing. Also, the seam traditionally found between writing media and learning media is disappearing. Traditionally, writers consulted books to learn how to write, for instance, a seminar paper or a thesis. Now, the writing tool itself contains the instruction from the books. The next section introduces one such tool, called thesis writer and demonstrates the kind of seamless writing it offers to its users.

3 Thesis Writer: An Example of a Seamless Writing Environment

Today, all of the aforementioned technologies are simultaneously in use. They depend upon each other and they support each other. Their complexity and pervasiveness in student learning is striking. Most learning is mediated by these technologies as today; almost no teaching is without an element of writing. However, the interrelation of new technologies with learning and their integration into teaching and working contexts is far from clear. Seamless writing as a concept may help track the impact of the new realities on student learning and the organisation of teaching. For an illustration, this section briefly introduces the main functions of Thesis Writer (TW), and explains its pedagogical rationale. For a glimpse at TW beyond Fig. 1, please open www.thesiswriter.eu. For a brief overview of TW, see Rapp, Kruse, Erlemann, and Ott (2015); and for an evaluation of TW, see Rapp and Kauf (2018).

TW is a new cloud-based bilingual (German, English) writing environment connecting writing with instruction on writing and research, collaboration, and supervision in a completely new way. To consider TW seamless is, of course, a keen attribute as reducing seams necessarily leads to new seams. It may be claimed, however, that traditional seams have been replaced in favour of newer seams which are more favourable to the organisation of thesis writing and the complex learning processes it entails.

The motivation behind the construction of TW was based on the observation that higher education students in Switzerland and Germany were considerably underprepared for their first theses writing experiences at the Bachelor's and Master's degree level. After three years of study, students are generally tasked with writing an extended research-based paper for their Bachelor's graduation with very little expe-

Fig. 1 Start page of Thesis Writer

rience, if any, in academic writing or research writing. The situation for Master's students is somewhat less dramatic with most having already written a thesis for their Bachelor's degree, yet they may face harsher standards of scientific scrutiny or scholarly precision in the evaluation of their writings. For university instructors, thesis supervision is a highly time-consuming and hence costly activity (if performed well) and forces them to repeat similar instructions to their students many times over. From an institutional standpoint, the management of thesis supervision for large numbers of students (e.g. up to 800 students a year in the authors' department alone) demands considerable manpower capacity (for a discussion of TW's contribution to scaling learning, see Rapp & Kruse, 2016). TW intends to support all three interested stakeholders—students, instructors/supervisors, and institutional management—and aims to help interconnect their activities better.

The construction principles of TW rest on two main ideas: A process-based approach helping writers to organise the writing process, and a rhetorical or genre-based approach, helping students to master the structural and linguistic aspects of their text. TW not only organises the writing process, but also helps understand and master the intertwined research process that usually forms part of the dissertation project. For institutional users, TW provides a customised, institutional page which offers the ability to add local instructions or standards on thesis writing and provides a communication channel for institutional users. TW contains some 100 short tutorials about writing and research, linked to different places of the platform and phases of the writing process in order to make them available whenever needed.

The workflow in thesis writing is guided by a roadmap (see Fig. 2) which separates the writing process into four separate stages. The first two stages deal with the preparation and planning of the thesis, while the third and fourth stages address data collection and composing/revising of the text. Each stage has a text editor with a number of support functions made available. When one stage is completed, the tool will transfer the text to the next logical stage where it may be connected with different instructions and different help functions.

The rhetorical stage is guided by an extended version of the IMRD (introduction, method, results, discussion) scheme which is referred to as the 'research cycle' (topic, research question, state of the art, knowledge gap, relevance of research, method, results, interpretation, conclusions, Kruse, 2016) as depicted in Fig. 3. This scheme is used to help students understand the main steps in planning and reporting research. They are invited to organise their own ideas and working results along the lines of this standard structure and are supported by several tools in order to understand the meaning of each section. This structural support is complemented by rhetorical advice showing writers which options they have, for instance, to formulate a research question or indicate a research gap. In the second step of the working process, writers receive support through in-built help functions to organise the research material they have gathered and to structure a report about their project in several steps of revision activities.

Additional support tools (see Fig. 4) for mastering the writing/research process are: (1) examples for each section of the proposal, (2) a phrase book (tied to each section of the proposal), and (3) a search tool for real-time queries from a large corpus

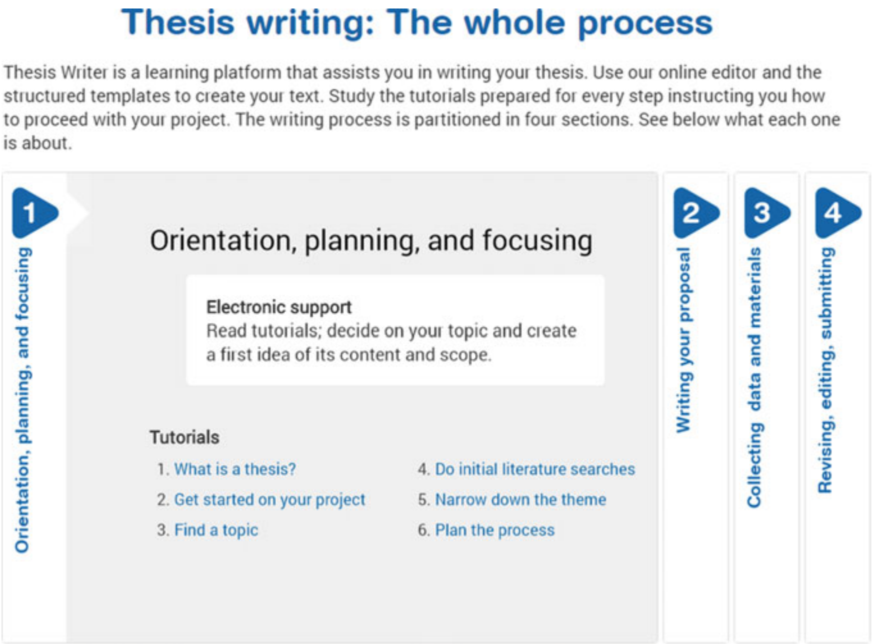

Fig. 2 Process approach of writing used in Thesis Writer ("road map")

Fig. 3 Research cycle, rhetorical structure used in Thesis Writer

of research papers. When writing their proposals, students can find these functions for each section of the research cycle and then select a number of typical phrases; for instance, how research communities would usually address a research question or indicate the meaning of their research.

Based on this short description of TW, it can be inferred which kinds of seams the learning environment removes or changes. TW demonstrates the high integrative

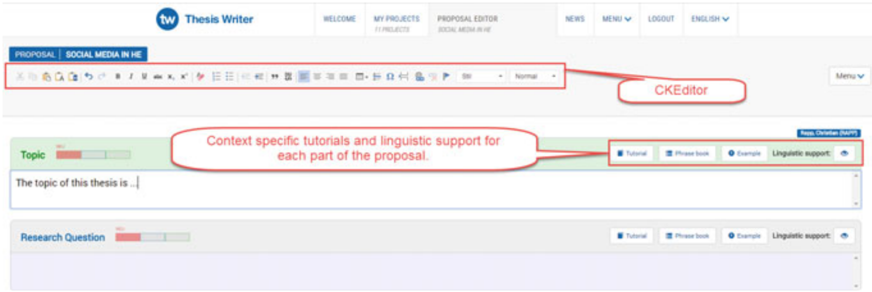

Fig. 4 Support tools provided in Thesis Writer

capacity which the platform has for connecting writing, learning, research activities, and the organisation of teaching. Some of the seams encountered clearly relate to those that Wong and Looi (2011) systematised in their review, even though it appears that seams have to be determined for each single task and learning context.

Not all of the 10 MSL dimensions described by Wong and Looi (2011) are relevant to writing. As described above, in writing seams such as restrictions in learning across time or location (dimension 3 and dimension 4) had already been superseded with the invention of paper, the pen, and the printing press. TW does, however, strengthen the ubiquitous access to learning resources (dimension 5), as compared to the conventional way of thesis writing. A learning environment like Thesis Writer changes the availability of learning opportunities and the access to learning resources. When considering changes in the relation of formal to informal learning (dimension 1) and of personal to social learning (dimension 2), it could be noted that a tool like TW considerably changes the personal meaning of writing and adds new opportunities for connecting writing with communication and virtual cooperation. In contrast, Wong and Looi's (2011) reference to the availability of multiple devices (dimension 7) is of only minor relevance in understanding the impact of TW on writing, as TW primarily depends on comfortable ways of text input by users of a computer or laptop rather than on the mobile quality of the devices. Nonetheless, TW is independent of both platform and device and is sufficiently responsive to allow for smartphone use. TW definitely changes the opportunity of 'seamless switching between multiple learning tasks' as proposed by Wong and Looi (2011, p. 20) (dimension 8) by connecting such tasks as orientation, planning, writing, feedback, and communication with others. TW breaks down the workflow of thesis writing to elements that had previously been carried out at separate places and reconnects them within the platform. In addition, TW leads to certain changes in the students' ability to synthesise knowledge (dimension 9), which is always a primary aim of academic writing. When students start working with TW, they should already understand the principles of knowledge construction and synthesis. TW then helps them to deepen their understanding of the basic elements of academic genres and offers new access to the constructing and synthesising of knowledge. Considering the 'multiple pedagogical or learning-activity models' (dimension 10), it is noteworthy to consider that thesis writing leads to new models of the writing/learning process, but that it unifies thesis writing rather than splitting it up into separate activity models.

The main seams identified (instead of seams they could also be referred to as problems, limitations, or obstacles for learning) can be summarising as four main dimensions:

(1) *Seam between writing and learning*: Learning to write and writing to learn are usually two different and differently taught aspects of writing. However, in TW, both are integral elements of the learning platform so that writers get help whenever they need it and do not lose time searching for solutions to their learning needs. The platform is arranged in a way that new help functions can be added when deemed necessary.
(2) *Seam between writing and research*: In thesis writing, at least some research activities are inevitably involved and the seam between writing and research separates into two distinct patterns of activity, with each consisted of different timing, management activities and thinking skills. While in writing, students have to sit, read and create text, in research they have to carry out activities such as searching for literature, conducting interviews, collecting data, looking through archives, or interpreting historical documents. Although this seam between these two kinds of activity will never disappear, it is proposed that TW better connects both activities and dissolves frictions in students' activity patterns.
(3) *Seam between writing and communication*: Traditionally, writing isolates writers from each other and separates situations where writing takes place from those where communication happens. TW offers users the opportunity to communicate while writing, for instance, by inviting other students or their supervisor to access and review a section of their developing thesis in order to receive immediate feedback and discuss the text. Additionally, collaborative writing can be done in TW without exchanging text through emails or learning platforms. All partners can write within the same document and propose changes or post comments.
(4) *Seams between actors or stakeholders involved in thesis writing (students, supervisors, and institutional administrators)*: The actions of these three stakeholders become integrated better than before. The tool provides a meeting place for all stakeholders and arranges their actions in a meaningful way.

4 Conclusion

Seamless learning is an approach aimed at conceptualising learning spaces with respect to their integration and contextual adaptation. The pedagogically sound use of digital technologies in education is able to bridge seams and offer new foci in respect to organising teaching and learning processes. Seamless writing contributes to this field by studying the uses of writing technologies within the workflow of individual learning and as a part of the management of student writing/learning within educational institutions. However, in comparison with the existing conceptualisations of seamless learning, different seams now come into focus and different ways of seamlessness may, therefore, need to be studied. It is anticipated that such research would not only help to refine the concept, but also increase its breadth.

In the past, two major issues and their consequence have been studied in the context of seamless learning: mobile learning, and the ubiquity of learning given the widespread and affordable availability of the respective technologies. Both, it can be said, have significantly changed the situation of learners and of learning itself. However, when considering the technological development in the field of writing, it has to be noted that digital writing technology has considerably moved the field towards ubiquity in learning and learning anywhere already a long time ago. Reading and writing could be practised wherever there was paper available, or a book, and adequate light from which to see. We suggest to de-emphasise the importance of the mobile and ubiquitous dimension in the seamless learning concept in exchange for a more cognitive and communicative view. A learning platform like TW organises student thinking anew and provides new ways of gaining orientation in this difficult task. It will be necessary to study the user patterns more closely and understand better how students gain from using TW and its various support functions.

Thesis Writer—does it produce new seams? Of course, as any cloud-based tool only works when there is an accessible Internet connection. Seamless learning may be a desirable goal for learning but similar to other value-based aims (please think of justice, health, or critical thinking), is also a fiction that never can be fully reached. Cloud-dependent tools like TW divide the world in places where internet is available from those where it is not. Working on a train might prove difficult when the train company does not provide Internet access. New seams were also produced between writing and other support programs like literature management systems, Excel spreadsheets, and graphics programs which, at the moment, cannot be integrated into TW due to current technical limitations. Of course, this may change in future, but should these seams be removed, in its place may be a seam that opens between different groups of students: Users who are not skilled in using technology or find TW too complex will become separated from those that can readily use the new tool. In this case, technology itself becomes a seam separating students from their learning opportunities. For this seam, there is no conclusive answer not as yet.

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