A Mixed-reality Interaction-driven Game-based Learning Framework

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ABSTRACT
In the modern information society, learning is no longer just about obtaining factual knowledge, but more about general skills on how and where to apply available knowledge and obtain new knowledge in order to solve new problems. Such skills include abilities to connect and organize ideas, fill gaps in knowledge structures, evaluate evidence, argue with new information, test and modify, predict, clarify, generate questions, learn new concepts, make unexpected connections, reflect, analyze, synthesize and loop back. This work presents the Immersion framework, a digital ecosystem for adaptive smart learning environments for interactive mixed reality driven methods to foster learners' self-regulating skill development.

CCS Concepts
• **Human-centered computing → Mixed / augmented reality**
• **Applied computing → Interactive learning environments**
• **Software and its engineering → Frameworks** • **Human-centered computing → Empirical studies in interaction design**

Keywords
Mobile Learning; Mixed Reality; Self-regulated Learning; Game-based Interaction; Technology Enhanced Learning; Learner Collaboration.

1. INTRODUCTION
For more than a decade now, education and educational standards have shifted the emphasis of teaching away from rote memorization and de-contextualized experiences, toward the development of concepts, processes and skills that promote scientific literacy. Scientific literacy involves critical thinking, cognitive and metacognitive abilities, collaborative teamwork and the effective use of technology to solve personal problems, engage in scientific discourse around global issues and persuade others to take informed action [1,2]. Constructivist pedagogy can facilitate the development of scientific literacy. For example, reviews of research examining inquiry-based approaches to teaching school science have illustrated substantial gains in outcomes on an array of quantitative measures, including cognitive achievement, process skills and attitude towards science [3-7]. Reviews of research examining problem-based approaches to teaching and learning, from middle school to professional education, have shown that problem-based learning(PBL) helps learners develop strategies for learning and construct knowledge that is transferable to other situations [8-13].

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Technology offers possibilities for creating learning environments based on constructivist pedagogy approach, so that the latter is empowered via technology as a tool in learning. Yet, although there is a growing research foundation in technology-enhanced and computer-supported constructivist learning [14-16], it is fair to say that the full potential of technology in supporting constructivist pedagogy and learning has been already exploited.

Today the abundance of digital technologies at our finger-tips, from smartphones to multi-touch surfaces, and our increasingly interconnected world, have unavoidably impacted higher education, offering new perspectives and approaches to interaction and learning.

This work formulates the Immersion framework that capitalizes on the aforementioned technologies to create learning environments that can promote constructivist pedagogy and learning. It is an educational digital ecosystem that is designed to accommodate mixed reality (MR) -also augmented and virtual reality (AR/VR)- on mobile and wearable platforms with game-based, interactive content creation for collaborative learning support across time-space and reflection on-and-in action. Both are important processes in constructivist learning and fruitful areas for educational research and development.

Technology support for collaborative learning within dynamic learning environments, pre-supposes that face-to-face and online interactions are intertwined. Classrooms are no longer bounded by time or space. In a classroom, physical (paper and pencil) and digital (e.g., tablets and smartphones) artefacts are used interchangeably during problem-solving activity [17,18]. Moreover, the use of social media and Web2.0 tools extend learners' collaboration and interaction beyond the classroom walls [19-25].

The rest of the paper is structured as follows: section 2 overviews the background and related work, while section 3 presents the proposed approach. Section 4 presents the concept and architecture of the framework. Section 5 describes the development methodology, while section 6 presents research methodology. Section 7 analyses the role of digital games, section 8 the mobile learning and section 9 the MR environment in education. Section 10 presents the findings of the phase I of user requirements and, finally, section 11 presents the discussion and future work.

2. BACKGROUND AND RELATED WORK

Constructivist pedagogy refers to a family of approaches to meaningful, experiential learning, including problem-solving, case-based, project-based learning, anchored instruction and inquiry-based learning. Constructivist researchers have illustrated for decades that engaging learners in real-world problem solving can deepen their understanding, flexibility in application and transfer of knowledge [8,9,26-29].

Technology can support for reflection-in-action and reflection-on-action. The process of reflection that helps learners relate their new knowledge to their prior understandings (e.g."What did I learn?","What more do I need to know?") has received particular attention in research and practice related to constructivist pedagogy [3,30]. For example, in problem-solving learning, students are expected to reflect both on the new knowledge gained as well as group processes involved in solving the given problem. Schön [31] made a further distinction between 'reflection–in-action' and 'reflection–on action'. According to [31], reflection-in-action is concerned with reflecting on practice while it is happening and allows learners to reshape what they are working on, while they are working on it; whereas reflection-on-action is concerned with thinking back on what learners' have done and understanding how their strategies contributed to desirable (or even unexpected) outcomes (e.g., lessons learned at the completion of the task [31]).

Immersion goes beyond the basic idea of adaptive learning. Starting from the state-of-the-art technology available today, we will develop smart environments that are adaptive to learner's goals and level of competence, and support learner's self-regulating skills development in an open game-based and mixed reality setting. Moreover, such environment will provide social collaborative learning. The goal is the smart blending and combination of targeted learning goals and methods. The proposed framework describes the methods derived by quality requirements in learning by concrete measurement of the learner feedback, interaction and experience. Game-based techniques ensure that the triggers and information are communicated between the environment and the learners. Such regulation enables the teachers to have detailed visual feedback on the learner involvement, understanding and reflection, on various levels of content provisions.

Incorporating mixed reality in game-based learning involves specific technical challenges. Incorporating mixed reality technologies to smart learning environments requires a complete integrated approach on user interaction, game-based learning design, creating and testing new and revisited metrics for self-regulated learning as the ultimate goal. Additionally, aspects in content creation, teacher adaptability to the metric feedback and gamification for learning, require a systematic quality control for optimal harmonization. Immersion requires advanced learning outputs, with quality measurements and key performance indicators (KPIs) that address the start-to-end smart learning environment design, deployment and assessment.

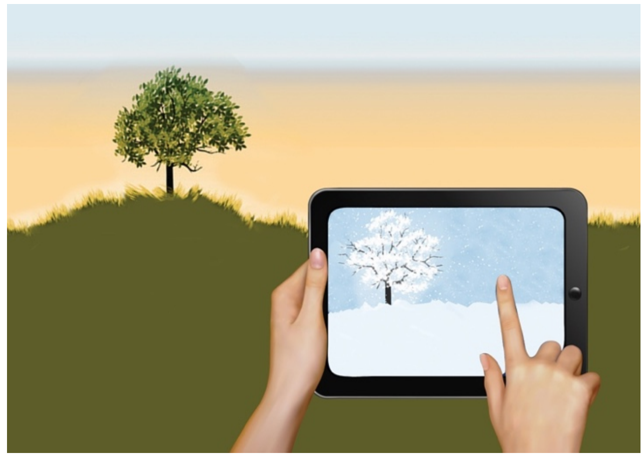

Figure 1. The MR "experiencing the four seasons" case.

3. THE PROPOSED APPROACH

The Immersion method key users are teachers and, by extension, students. Teachers may use the Immersion framework as a learning platform to quickly create and deploy an elementary school course on the weather and nature. Students may use their tablet camera to see their real-life surroundings, such as a tree right outside the schoolyard, a familiar point of interest (Figure 1). Augmented reality layers may be used to show the tree and surrounding grass as it would be in the winter and the other seasons. Depending on the actual tree and the geographical location, real weather data may be used to render the tree exactly as it usually is during the winter in that specific location. The real content and rendering help the students understand better the target concepts. The students may interactively explore other trees and scenery, trigger wind and rain. Some may choose to learn more about the trees, how they are when blooming or falling their leaves, while others may explore all information on the weather seasons. This flexibility helps cater for the individual interests, essentially personalizing some aspects of learning.

The learning environment also provides incentives for students to explore and complete their course, by showing remaining learning items (progress), hinting or providing gamification-driven bonus feedback to students that explore. The interaction itself reveals optimal paths that the student may follow according to their interaction choices, interests and learning goals. The interaction feedback can be logged and analyzed to assess the young users' expectations of the technology that they use, points that they may not seem to understand on how to progress, find content, and more. All the above data may then be analyzed and reveal hidden learner concepts based on their expectations of the potential of the technology and the learning aspects of the course. Additionally, the students may access the progress of their co-learners, share newfound information that they believe that may be of interest to the rest of the learners, and later discuss their rationale on how they chose to learn (paths, logical deductions, completeness, experience, etc.).

4. CONCEPT AND ARCHITECTURE

In Immersion, the notion of smart learning environment for self-regulating skills development, is that of an integrated environment, for creating immersive learning applications using highly interactive technologies. The concept follows a well-established multi-tier architecture paradigm (presentation tier, business tier and persistence tier).

The trans-disciplinary considerations of this work lie in the role of assessment and feedback, as a data stream from the learners, to the system, to the teachers and back. Creating an adaptive learning environment requires finding optimal ways to leverage the learning design, the information streams analytics that should be further researched in terms of feedback and assessment analysis, and the use of highly interactive immersive technologies to support and achieve such endeavour, namely mixed-reality and gamification.

Gee [32] describes digital games as goal-directed, problem-solving spaces, which can produce deep learning, while also fostering collaboration and productive discussions about shared experiences. Despite their potential, a study by the European Schoolnet [33] indicates that games are hardly used in schools around Europe, while the scene is not much different in the interactional arena [34].

At the same time, the emergence of augmented and mixed reality applications has the potential to revolutionize learning opportunities that intertwine playful learning and collaboratively investigating problem-based scenarios, enabling immersive learning opportunities with students moving throughout real-world locations, interacting with multi-modal information and collaboratively investigating problem-based scenarios [35,36]. Further augmenting these environments with learning analytics and artificial intelligence can cultivate further support for self-regulated learning. Therefore, the Immersion architecture is designed for mixed reality and smart learning environments, which will afford interaction with content and among learners as well as self-regulated learning.

The research-oriented Immersion concept of self-regulated game-based learning is realised by the Immersion learning environment architecture that is comprised of three tiers, data, business and presentation (Figure 2). The core development relies in the business tier where the mixed reality (or augmented/virtual reality) software is developed or deployed, the user experience (UX) and interaction design (IxD) modules, the predictive analytics engine and the gamification module.

The framework enables educators to author content via appropriate user interfaces, as part of the mobile learning platform. The learning content description is essentially a course where the educator may choose the learning goals, milestones, learning levels, user interaction required, in-course tests, allow free exploration, opt to record and analyse user feedback, provide strict scenarios or free-to-explore. The latter may trigger the system predictive analytics planner that may collect data on the user interaction, revealing content according to certain levels of difficulty or flow parameters and proposed routes to learners.

Educators may view the real time collection of data via the report dashboards. After the end of a course, the report dashboards provide a concise report visualizing the learners' progress (e.g. a learner-by-learner or grouped breakdown of the learner interactions), highlighting difficulties faced by learners and suggested plans (assessed by the user interaction) in order for learners to be able to accomplish their learning goals. This feedback allows for concrete recommendations by the system on certain changes that will foster or result in better learning for the learner self-regulating skills. All metrics utilise the mobile technologies (such as tablets) and MR to enhance the learning process and trigger self-regulated learning events.

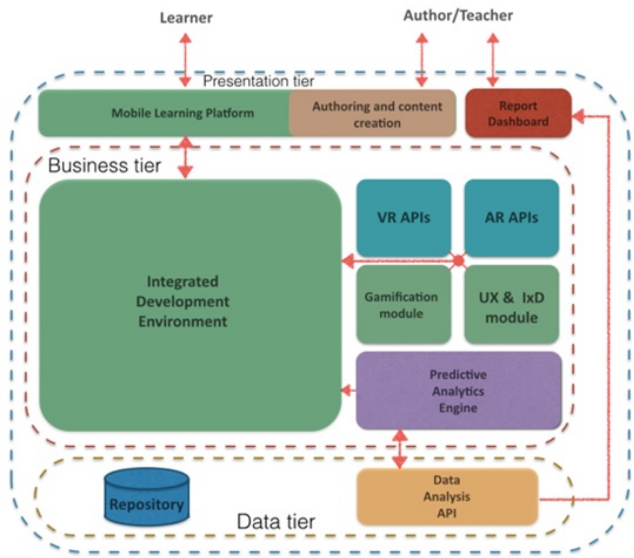

Figure 2. The Immersion framework architecture.

The approach requires the following key development and technologies to achieve the real-world learning targets (Figure 3):

- Reports on evaluation experiments assessing effects/impact of interactive interfaces and game-based learning approaches on the effectiveness of self-regulated learning, specifications of evaluation metrics based on data analysis and predictive analytics, as an automatic expert approach, to scenario design and re-design.
- The overall engineering approach, including specific design guidelines and developer tools allowing the integration of self-regulated learning skills training in immersive, adaptive game-based interaction using mixed-reality technologies.
- Creation of re-usable data collections, including semantic annotations of various types, software components, open source APIs, meta-information and metrics for assessment, and design.

5. DEVELOPMENT METHODOLOGY

The Immersion approach follows an iterative design approach. The basic idea behind this method is to achieve the learning outcomes from the framework through repeated cycles and in specific steps at a time. The evolving versions are iteratively enhanced until deployment, while the overall process is divided into four core-stages: planning, implementation, testing and evaluation. The first phase subsumes planning of all tasks that will be implemented in the next step. To give an example, in case of a game-based learning scenario, it includes arrangement of game design elements, game mechanics and a compelling story. One goal of this phase is to work out gamification mechanisms that can be deployed to intrinsically motivate player's actions.

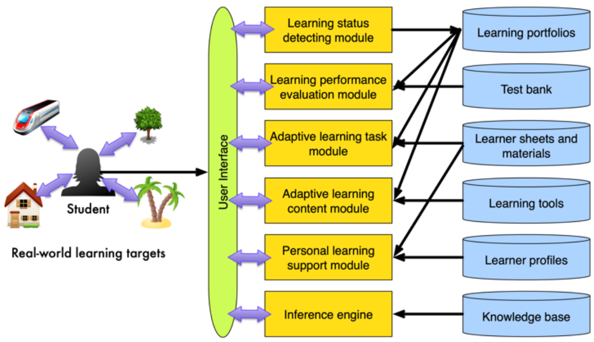

Figure 3. The Immersion learning target implementation.

Concerning the appearance of the scenario, a range of so called "wireframes" is prepared, which are non-graphical tem-plates, as well as rapid mock-ups to drive good user experience and information architecture. In a next step, the graphical user interface is designed - which defines the "look and feel" as well as the most important design templates.

As soon as the planning phase is finished, a first prototype of the scenario is developed. In the so-called "vertical slice" approach a small subset of the scenario is fully completed, including the functionality of the final system. A representation of the overall product is created, that offers valuable insights in the effectiveness of selected functionalities and usability of designed interfaces.

Quality assurance methodologies accompany the production process from the first prototype to the final release of the scenarios. An iterative Q/A approach should fix bugs early in the process and avoid delay in the later implementation phase.

After the completion of the first version, learner acceptance is evaluated. This is especially interesting, in order to see if any incentive scheme is capable of changing a participant's habits and motivations, from external to more intrinsic and hence more sustainable ones. Feedback is then evaluated and flows into the next iteration circle that starts with planning of further implementation steps. The first version of the scenario is now iteratively enhanced until it is ready for deployment.

The Immersion approach brings mixed reality technologies into the world of self-regulated learning on the bases of serious games. It builds and validates the Smart Learning Environment for developing and implementing learning interventions for self-regulating skills and strategies training.

The framework builds an integrated adaptive mixed-reality environment and components for all skills needed, in a highly complex competence. These skills range from low level behavioral skills, such as touch, browse, click, to strategic dimensions of learning, e.g. by presenting similar materials in multiple contexts, enabling self-reflection and having learners engaged in "what if" problem solving, that will prompt them to think more actively about the qualitative effects of varying particular problem parameters. By becoming consciously aware of different strategies and the way they work, the learners will be able to use them to monitor and improve their own thought processes.

6. ON THE ROLE OF DIGITAL GAMES

A lot of research has been done to understand what makes games so motivating and how learning content is integrated to facilitate an intrinsic learning process. Gee [32] posed the compelling question: "Why are people willing to put so much time and effort into learning to play extremely complex video games?". This seems obvious when we think of the high degree of interactivity and excitement that modern games offer to their players. To complete a computer game, players have to go through a self-directed and intrinsically motivated learning process, whose complexity outperforms a learning process guided by school curriculum by far. Several scientists, with Gee leading the way, consider digital games as "pure learning machines". Garris et al. [37] introduced a model of game-based learning that shows how learning can be improved by exploiting a game-based approach. The instructional/educational model shows the content the player absorbs during the process of gaming. To actually create an educational game, the educational content is combined with game characteristics. Once these two components successfully merge, they trigger the game cycle consisting of judgments, behavior and system feedback.

Digital game-based learning makes perfect sense by teaching in ways that other methods seldom do. It appears that the extraordinary level of engagement is caused by the enjoyment of the learning process. Fun creates relaxation and this in turn enables learners to absorb information more easily. Furthermore, motivation enables them to put in extra effort without resentment [38].

Immersion is designed to utilize the positive characteristics of digital games to create a dynamic and experience-driven learning platform. Instead of creating unintuitive educational add-ons, information should be well integrated into the game logic and the overall curriculum. It is all about the creation of long-term knowledge that in ten years will still be remembered - knowledge and insights that, in the future, lead to much better decisions. In the Immersion framework this is achieved through the creation of dynamic, experience-driven and inter-active virtual exercises that change the role of the learner from being passive observers to active participants (Figure 4).

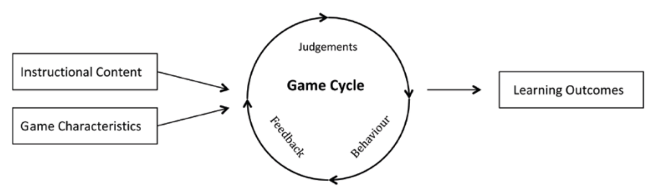

Figure 4. The Immersion learning approach.

Games benefit from their addictive and immersive nature. Players spend hours attempting to solve problems and unravel complex puzzles, frequently failing and restarting, to achieve progress in the game. This fact holds a huge potential for Serious Games to communicate knowledge in an effective and entertaining way. If such energy, enthusiasm, and determination were to be applied to "real" problems, so the argument goes by [39], then considerable benefits and progress could ensue. Indeed, players could learn some skills better from playing games than from conventional training. To provide validation for this claim, the Serious Games Institute undertook studies predicated upon the notion that virtual worlds can be effective for learning and training and are focusing upon the strengths of virtual worlds for supporting training distributed groups in their use of emergency response management training methodology and application [40].

7. MOBILE LEARNING

The idea to use Mobiles for Learning has dramatically evolved in the last years, as well as the mobile technology itself. Initially one of the main questions was how to make content accessible via mobile devices today more the integration of mobile devices in complex learning scenarios and the orchestration of learning support with different mobile devices came into focus of research and development.

In general, there still is an ongoing debate about how to de-fine mobile learning, either based on the technological infra-structure, the mobility of the learner moving across learning contexts, or the embedding and connection between the learner and the infrastructure. Early definitions have been coming mostly from a techno-centric perspective, defining mobile learning as: "any educational provision where the sole or dominant technologies are handheld or palmtop devices" [41]. As a next step the mobility of the learner became more and more important in definitions which led to approaches as: "any sort of learning that happens when the learner is not at a fixed, predetermined location, or learning that happens when the learner takes advantage of learning opportunities offered by mobile technologies" [42]. A comprehensive overview is given by Traxler [41], who summarizes the developments and different perspectives and criteria for categorizing mobile learning support.

In a more detailed analysis by Naismith et al. [43], new possibilities of mobile learning support have been analyzed according to different educational paradigms and learning activities as behaviorist, constructivist, situated, collaborative, informal/lifelong, and support/coordination. Some educational and instructional theories are prominent in the mobile learning domain. Situated cognition suggests that learning is naturally tied to authentic activity, context and culture [44]. Situated learning is referred to as learning that takes place in the same context as it is applied [45]. Donald Schön's concept of the reflective practitioner [31] is another important theoretical foundation that is often used as underlying theory for mobile learning projects especially for contextualized learning and different situated reflection perspectives. Authentic Learning focuses on real-world and complex problems and solutions for them. Learning environments are often not artificially constructed but real problems and their multidisciplinary challenges are taken as the starting point.

Mobile learning can be supported in formal settings as classrooms and also in non-formal and informal settings. Most prominent usage of mobile technology in educational settings is up to now field trip support with mobile technologies. As mobile technology gains importance as gaming platforms, using the technology for serious educational games is a promising approach.

8. MR ENVIRONMENT IN EDUCATION

Education, which is an area that provides ideal settings for the adoption, has adopted AR and VR for teaching and learning situations [35,46]. The advantage of this is that it enables large groups of students to interact with each other as well as within a three-dimensional environment. It is able to present complex data in an accessible way to students, which is both fun and easy to learn. Plus, these students can interact with the objects in that environment in order to discover more about them. In general, VR applications in education have followed three major directions:

1. Collaboration in VR classroom to foster social integration of learners [47]; using the Oculus Rift headset, the study enables tech- and science -inclined students to become accepted by their peers, by visualizing and demonstrating their skills in a virtual environment.
2. Enabling the safe and cost-aware exploration and experimentation of hard-to-reach sites; applications range from virtual tours at historical and archaeological sites, to experimenting in a virtual replica of a building construction site [48].
3. Increasing the students' motivation and reward via VR gaming-based approaches; using the Oculus Rift headset, students can exemplary collaboratively building structures in Minecraft, obtaining knowledge on architecture, landscaping and building statics whilst playing a popular game [49]. It is also worth noting that Massive Online Open Collaborative (MOOC) games are also a prosperous ground for VR applications in education [46].

Finally, we mention that the relatively expensive Oculus Rift headset, employed in VR applications in education, can be substituted sufficiently by extremely inexpensive alternatives, such as Google's "Cardboard" [50,51]. Other headsets have also found use in the VR-enabled educational applications, such as Epson's "Glasses", albeit to a lesser extend so far [52].

Recognizing the value of constructivist teaching and learning, the Immersion approach utilizes affordable technologies to create leaning environments that can nourish constructivist pedagogy and learning. We leverage technology support for the constructivist classroom with a focus on supporting (a) collaborative learning across time-space and (b) reflection on-and-in action during problem-based activities. Complex setups and systems based on installations, tangibles, AR/VR, or MR are not easy to find or install in classroom settings; such systems are costly and not easy to use without (technical) support for learners, but also instructors. As a result, their use rarely extends beyond laboratory settings, leaving their potential practically invisible and unexplored. In this work, we seek to design and deliver simple-to-use, easy-to-integrate technologies for learners and instructors, within the spirit of supporting constructivist pedagogy.

9. USER REQUIREMENTS – PHASE 1

For the design of the framework, we collected requirements on the general objectives of the proposed framework, based on which the concept and the design, as described above, were based. Two schoolteachers and their students (N=32) of final grade K-12 elementary (age M=11.5 years) were provided with paper mock-ups of the reflection approach and static VR screenshots on iPads depicting the weather seasons (two per season) from the school door looking at the courtyard. The teachers were asked to direct the students (in groups of 4 per display) to browse through the images and discuss their findings. They were also asked to discuss in-group and voice their follow up queries to learn more about the task. The teachers overviewed the learning outcome with follow up questions and discussion as they do normally in class with the additional logging of the student interaction (between-group and voiced to class). The teacher debriefing and discussion led to the following generic user requirements for the Immersion approach:

- Content authoring for teachers and instructors to use with gamification and mixed reality for game-based interactional design and user experience evaluation methods, in order to advance the learning process at school.
- Integration of the self-regulated learning process to the proposed MR-based approach and extract rich data from the learner-system interaction.

- Achieving learning and skills training with (i) effective and adequate learning experience (completeness), (ii) impact on the level of measured gained learner skills (quality) and (iii) user experience (acceptance).

10. DISCUSSION AND FUTURE WORK

The Immersion framework is an ecosystem that enables self-regulating skill training, based on the integration of re-search on constructivist pedagogical approach and actual training in multiple simulations within mixed-reality environments in a game. The value proposition has to do with learners' ability to collaboratively learn, effectively monitoring their learning and creating the means to self-regulated learning, aiming to help students learn how to learn, and train the skills that are essential to fully enable constructivist pedagogy. The proposed framework leverages adaptive learning, constructivism and game-based social learning and technologies, such as augmented reality and virtual environments

Specific concerns, voiced by teachers, are the training needs on the technology, the re-usability and the need to collaboration for the content authoring and the sharing of content between educators. The costs to acquire the MR hardware is also a major issue, that is partially mitigated by the fact that there are specific low-cost offerings on VR glasses as well as open source tools and methods for content creation and delivery to class, that are quality-tested in real-world environments and contents.

Our future work includes the deployment of the approach on a similar size and type participant group, which will fully create content and use in class for two-hour sessions, to allow for user feedback on the learning outcome and reflection, as well as usability testing. Finally, it was suggested that personalization aspects could improve the basic adaptability of the approach to broader education and training targets, such as social skill training [53-59] and collaborative filtering techniques [60-67].

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