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Games on Mobiles via Web or Virtual Reality Technologies: How to Support Learning for Biomedical Laboratory Science Education

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Abstract: Simulations, serious games, and virtual reality (SSG) applications represent promising support for achieving practical proficiency, but it is difficult to know how to introduce them into a new environment. This paper aims to contribute to a better understanding of introducing new SSGs to a non-computer related educational environment—biomedical laboratory science (BLS) education. By following the choice, construction, and evaluation of a gamified app for practicing phlebotomy (StikkApp), not only the usefulness of the application, but also the general needs and possibilities for supporting SSG applications, are discussed. This paper presents the evaluation of StikkApp through an experimental study examining its use on mobile devices, as a web app and by discussing challenges for a corresponding virtual reality app by BLS students and their teachers. This evaluation focused on questions concerning usage scenarios, technologies, and how the design of the app can be aligned to learning goals necessary for education. By discussing these requirements and possibilities for apps and technology support for using SSG apps for BLS students, this paper contributes to a better understanding of using digital support for sustainable education.

Keywords: game-based learning; biomedical engineering; education; phlebotomy; evaluation of educational games

1. Introduction

Schools and educators embrace digitalization and new technologies, but they often struggle with choosing the right technology and strategy for achieving better digital support for students' learning [1–3]. There is much negative experience associated with digitalization processes of education: price, hidden costs, extra resources needed for the introduction, and a lack of clear guidelines [4]. Digitalization is difficult to anchor in education settings with limited digital experience [5] or with instructors with little or no existing technical skills or interests [6]. To fully utilize digital or serious games, important limitations could include the following: lack of knowledge about how to align the aims of the games to the learning goals, unintended side effects from the digital transition [7], or missing game elements that allow for in-depth learning [8]. This is mainly due to difficulties concerning how to systematically introduce and assess effects [9] or illustrate empirical benefits [10]. Tsekleves and his colleagues stated the following: "it is yet unclear how serious games can be best incorporated within formal education systems" [11]. This is a major problem that is present even before the actual use of the games, and it is one of the motivating factors of this paper. However, despite the reported difficulties, according to several review papers, the benefits of their use seem to outweigh the obstacles [3,8,12].

Looking at the general benefits of serious games, one can consider the biomedical laboratory science (BLS) field well suited for using these solutions, with potential benefits being improved robustness, access, and simulation of dangerous or erroneous situations that could otherwise harm the participants. Both immersive technologies, such as VR and AR, and non-immersive mobile and traditional computer games can be effective in this area. The challenge here lies mainly in properly adapting them to the educational content.

Current BLS education encounters several challenges, such as (i) limited resources and time at campuses, (ii) limited resources and time at supervised professional placement fields, and the major challenge of (iii) how to reproduce the up-to-date conditions (or elements of the conditions) of an authentic working environment [13,14]. Such a simulated environment would allow for learning about the environments and tools at a workplace, thus easing the transition phase from the educational institution at a much earlier stage and enabling focus on workplace-related activities. Many aspects of the environments related to work processes and available technologies that are usually found at these professional placement fields can be learned earlier. One of the potentials of digital technologies, especially simulations, serious games, and virtual reality environments (SSG), is support for up-to-date, authentic learning experiences with high presence [2,15].

When utilizing digitalization in general and SSGs in particular to complement educational activities and improve learning and teaching, an important question is the following: which of the available technologies do we choose and how should we apply them? This is a non-trivial question that leads to many follow-up questions, often related to the actual context. Currently, students and teachers are already using digital solutions, e.g., web-based learning, such as ePraksis.no, and support for flipped classroom activities.

The overall goal of this study is to contribute to our understanding of initializing, developing, maintaining, and integrating SSGs in BLS education. This knowledge will contribute to finding ways to estimate the added value of SSGs for teaching and learning. The first step towards reaching this goal was to identify relevant problems needing support that could be translated into goals in SSG applications in order to enable better learning. We wanted to construct a small but important application with clear learning goals for the BLS environment. After discussions with teachers and reading the literature, a gamified application for practicing the phlebotomy process was chosen. It is called StikkApp, and it supports the learning outcomes associated with venous blood sampling. The application was developed and evaluated first as a mobile application, mStikk [16], and afterwards as a web application, wStikk [17]. During the evaluation of wStikk, arguments for developing a virtual reality (VR) or augmented reality (AR) application (xStikk) for the same learning goals were discussed. During the same evaluation, the general applicability of SSGs for several other learning goals and the possibility of using different technologies were also discussed. This paper comprises data from these two experimental studies to contribute to the understanding of the general applicability of SSGs for BLS education.

To avoid potential confusion related to different vocabularies in the field, we need to explain some terminology. Many researchers use the expressions "serious games" and "gamification" interchangeably. "Immersion" has different meanings in the game research field and in studies focusing on technology development and use. This study defines "serious games" as games created for computer technologies intended to support learning and teaching in contrast to typical entertainment games [18]. "Gamification" refers to computer technologies, applications, and methods enhanced with game elements and designed to make existing technologies, applications, or practices more challenging and enjoyable for users. "Simulation" refers to simulator technologies allowing users to experience environments or activities that imitate real life. An important characteristic is that these environments and activities are not necessarily easily adjustable to different contexts: e.g., a car simulator technology cannot be used to support experiencing house interiors. We use the term "SSG" for all technologies and applications supporting simulations, serious games, gamification, and virtual environments (virtual reality technologies and applications). For this paper, the technologies studied are simulation and serious games but may also include elements of gamification or AR or mixed reality (MR) technologies; hence, the SSG abbreviation is used in a broad sense. By "presence", we mean the relative sense of believing that you are in the computer-generated environment instead of a real-life setting [19]. The term "immersiveness" relates to the objectively measurable properties of technologies (e.g., Head Mounted Displays (HMDs), HoloLens, Oculus Rift) providing surrounding experiences to the users' senses [20]. Here, we need to mention that studies from the field of game research use the same word "immersive" to indicate great experience. High presence is not necessarily made possible only by the use of high-end technology but also via engaging applications.

In this study, we intended to provide a general understanding of how to support BLS education to become a sustainable form of education with SSGs. However, the currently available applications, the local context at Western Norway University of Applied Sciences, and how BLS and computer engineering education cooperate may have influenced the results. The examined technologies were tested by typical users, but not in class (yet), which may have also influenced the results and discussion.

This paper is structured as follows. Section 2 describes the demand for digital development in education and the BLS field as well as an overview of the possibilities provided by SSGs to aid in this effort and an overview of the current digital solutions available. The study design for both studies this article is based upon is provided in Section 3. In Section 4, the results of the studies are reported. We provide an interpretation of the results in Section 5, along with our recommendations for how to create an SSG for BLS education, with a focus on dealing with the requirements and resources in the current environment. Suggestions for future work can be found in Section 6. Finally, Section 7 contains our conclusions.

2. Background

To provide a basis for how to support BLS education with SSGs, we will describe research on thoughts and activities regarding digitalization in BLS education, experience regarding the benefits and limitations of using SSGs, and knowledge about existing approaches and environments that allow for this support.

2.1. Experiencing Demand for Digital Development in Education and the BLS Field

The use of digital technologies in education continues to increase and evolve for several reasons. First, there is a demand on teachers to improve and expand their use of digital technologies in teaching [14,21]. This can be seen from the increasing use of concepts of digital competence and digital literacy in public discourse [1] and in white papers from government and higher education institutions (HEIs) [13]. Second, the demand is supported by compelling evidence that the use of digital technologies in education could be cost-effective [22,23]. Third, when properly utilized, users of digital education report increased engagement and learning outcomes [24], a perception supported by several systematic reviews and meta-analyses [25–27].

How to interpret digitalization and implement digital solutions is highly relevant [1]. Some implementation can even be detrimental to learning. An example of this is recording lectures and directly posting the videos online or the large focus on the digitization of text-based material without requiring student involvement. This may increase the availability and flexibility of working with the content, but if no other measures are taken, the much-important involvement of the audience can be lost [28]. More involvement can result in increased feedback and engagement [11,29], and there is a close link between the engagement of the learners and their learning outcome [30]. This motivates studies that investigate how to acquire and best utilize digital tools for learning goals [31]. This is important as students frequently request more interactive and engaging learning opportunities, and they appreciate less reading of books and one-way lecturing [32,33].

To ensure that a learning environment promotes the acquisition of the necessary theoretical foundation and effective ways of acquiring practical skills, several studies argue for a blended learning approach [34]. For this approach, the focus should be on exploring ways of creating interactive and engaging content that integrates the theories into practical skill training [35]. The creation of engaging and supportive digital learning content can be challenging [29]. It is highly dependent on the learning context, the exact problem to be solved, the curriculum, and the stakeholders and their preferences [20]. Additionally, it is difficult to know how to choose the appropriate technology or technologies for a particular type of problem, how best to benefit the learners, and how to create content suitable for the learning platform [36].

Students in biomedical laboratory sciences must achieve a solid theoretical foundation as well as high proficiency in practical procedures. The field of BLS is of the utmost importance to modern society as it is a fundamental part of medical diagnostics and is thus vital for the running of hospitals and general practitioners [37]. BLS students must be able to perform many procedures with skill, knowledge, and proficiency in order to obtain as accurate analytic results as possible and to avoid contamination or errors of samples [38]. There are calls to improve the skills and productivity of BLS practitioners as well as to expand their role, e.g., by means of using more digital solutions [10]. The Norwegian guidelines for BLS education and other white papers from the government and the Norwegian Institute of Biomedical Science (NITO) stress the importance of digital competence, as well as the need for future BLS to obtain generic skills during students' bachelor education [13]). This leads to a demand on teachers and study programs to improve and expand their use of digital technologies to enable active learning (see further discussion regarding these issues in Section 5.1.

2.2. Possibilities Provided by SSGs

This study focuses on providing a better understanding of how to define supportive structures for the introduction and use of SSGs, thus some of the benefits and potential for new possibilities in using them need to be mentioned. According to several recent review papers [2,8,10,39], there has been a large increase in interest in SSGs during the last decade. While there are negative aspects related to this type of learning, there seem to be more positive experiences. Some reported benefits of using SSGs in education include the following: increased motivation, higher presence in the digital simulation compared to many real-world simulations resulting in more realistic experiences, possibilities of simulating issues that cannot be trained in reality (e.g., making errors and seeing and handling their consequences), training at a distance, allowing follow-up activities rigorously, and possibilities for mass training and performing evaluations based on the same premises [12,40,41].

Recent studies show that the quality in clinical laboratories "cannot be assured by merely focusing on purely analytical aspects . . . in the delivery of laboratory testing, mistakes occur due to pre-analytical factors (46–68.2% of total errors), while a high error rate (18.5–47% of total errors) has also been found in the post-analytical phase."(46–68.2) than [42]. Because digitalization and simulation provide the opportunity to learn clinical skills in the context of everyday work/hospital environments [43], several education settings imitate learning places using simulation technologies [36].

SSGs, similar to other technologies, must be carefully chosen and adjusted to the specific learning situation [11,44], and from the very start, responsible teachers and instructors should know how to evaluate their effectiveness [9]. It is important to keep in mind that SSGs are not only tools that need to be adjusted and used, but tools and applications that need to be continually developed.

2.3. Existing Digital Solutions Supporting BLS Education

In current BLS education, there are a growing number of initiatives and products relating to educational innovation using technology, including the following examples: At Western Norway University of Applied Sciences, most medical laboratory courses in the BLS study program utilize e-learning tools available on an open-access web page [45]. In the BioDigi project [46], BLS study programs in Finland have developed a digital study portal with central study modules that all partner HEIs can utilize. Additionally, in Finland, Future Technologies in Education [47] is developing a working life-based virtual learning environment to serve biomedical education. Commercially, Labster develops and offers commercial virtual lab simulations for BLS-related courses, e.g., within hematology or cellular and molecular biology [48]. Several North American universities, including Florida Gulf Coast University in the USA, offer complete BLS study programs as online courses [49]. Most of these educational institutions demand additional laboratory training and supervised professional placement in order to complete such BLS programs.

These current digital environments for BLS education generally fall into two categories: they are either expensively licensed [50] (+Praxilabs), or they are lacking the immersive engagement of using SSGs [46,47,49]. An example of the first category is Labster [50]; it is an environment supported by being a paid product, cooperation with universities around the globe, and external funding. While aspects of their solutions show great potential [51], the pricing can be prohibitively high for many institutions, and adaptation of the solution cannot be performed by the institution itself, making it reliant on the company as an external partner. Such adjustments might be necessary for helping students to ease the transition when entering the workplace and to ensure adherence to local regulations. On the other hand, we have environments such as BioDigi, which are freely available, but do not utilize the potential of SSGs. This specific example currently has edX-based courses with videos and quizzes that can be used as part of the learning process [52].

To better support current teaching methods and further aid instructors in providing their skills to future BLS students, we must consider new and specially tailored tools. The development of such tools should focus on improvement through integration into current learning situations, for example, by providing students with engaging self-study opportunities.

The BLS education program at Western Norway University of Applied Sciences has been developing short videos published on a WordPress webpage (ePraksis.no) via their YouTube channel. ePraksis.no is an open-access learning resource with a collection of short videos demonstrating essential laboratory procedures and instruments to be used in several of the medical laboratory courses, as well as during work placement in clinical laboratories at hospitals. To explore the possibilities of computer simulations, virtual/augmented reality, serious games, or gamification for BLS education, the interdisciplinary research group EduGameLab was established in 2017. The group consists of educators and scientists at the BLS and ICT (Information and Communication Technology) engineering education programs and aims to start collaborative research and development projects.

3. Study Design

As the first step in EduGameLab, BLS-relevant learning situations needed to be supported, and possible SSG applications and suitable technologies for this support were identified. Educators from the BLS environment prioritized the phlebotomy process as a current, critical, and difficult learning program. All BLS students must learn this procedure, which includes several steps that they should perform automatically. However, they only have a few opportunities to practice in laboratories. The educators named the SSG application(s) aimed at supporting this learning process, StikkApp. The next step was to define interesting research and development projects and recruit ICT engineering students at the BSc and MSc level. First, a group of BSc students in computer science/engineering were recruited and engaged in designing, developing, and evaluating the usability of the mobile application, mStikk [16], which was further developed as a web application as part of our research project [17]. This paper comprises these two earlier studies and further examines thoughts and opinions from the interviews done after evaluating the web application.

The development of the prototypes conducted thus far has relied on the guidelines from Oates for design and creation [53], as well as evaluations based on suggestions by Mankins to support and differentiate essential testing activities, from idea creation to practical integration of the new app in the usage context [54].

3.1. mStikk

mStikk was developed as a bachelor project in computer science and evaluated by six BLS students in their second and third year of the program (spring 2019). The first prototype was developed as a mobile application by reviewing the literature [55] and films at ePraksis.no and observing the procedure in practical settings. The early development process was initially reviewed by two teachers from the BLS field and one in interface design. This part of the early development phase was crucial in guiding the later stages of development in a direction that made the application attractive from an educator's point of view while also ensuring the correctness of the content and having a well-functioning interface. Further development was then performed based on the feedback that was gained from the users.

This was done by identifying a BLS problem, choosing state-of-the-art technologies that enhance the engagement of the students, iteratively developing the learning game in close collaboration with educators and students, evaluating the games (first mStikk and after that wStikk), and finally estimating benefits and limitations uncovered in the process. An essential aspect of the app is "gamification" of parts of the procedure. Figure 1 presents an example of this, where students need to learn which blood tubes to choose for phlebotomy. Identifying the correct tubes leads to earning points, while points can be lost by identifying incorrect ones.

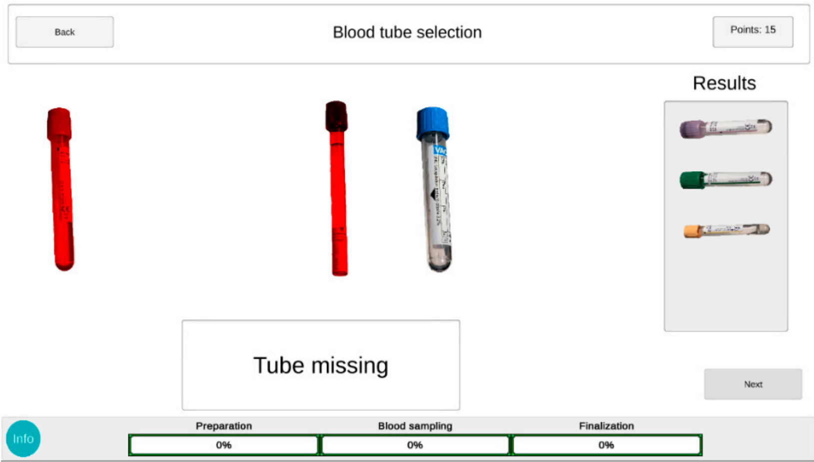

Figure 1. Identifying the correct tubes is essential for learning phlebotomy.

The final stage for the mStikk prototype was a qualitative test performed by six test persons. They were three second-year and three third-year BLS students. They attended lab courses frequently throughout their studies and thus had previous phlebotomy experience. This gave us the perspective of students who had already gained some proficiency in the procedure, yet still had recently experienced the current teaching methods. Each test lasted around 10–15 min, with hands-on testing of the application, followed by semi-structured interviews based on eight questions about their performance and experiences of the app (see further [16]). The testing procedure was carried out by the two bachelor students.

3.2. *wStikk*

After the mStikk prototype had been tested, we proceeded to create a web version of the StikkApp, named wStikk (see Figure 2). Our goal at this stage was to use the feedback gained from the mStikk project to perform further development and enhancements. Doing this, we aimed to get valuable insight into aspects such as whether a web version was positively received and whether the improved gamification factors played a role in the engagement of the students.

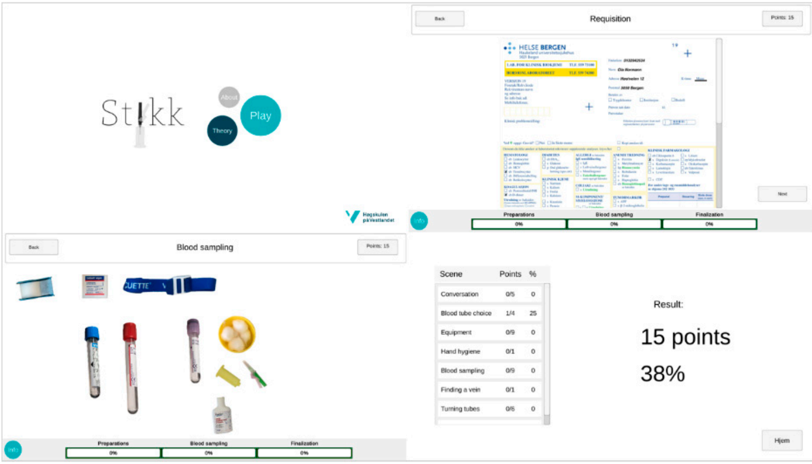

Figure 2. Selected parts of the wStikk learning game.

The web-based application, wStikk was developed as part of the research project and evaluated by three user categories: three experienced teachers (average age 61), three students familiar with the phlebotomy process (average age 23), and three inexperienced first-year students (average age 20). Test persons performed the game procedure twice, first with instructions from the experiment leader and after that on their own. Their performance was recorded, time was taken, and semi-structured interviews were performed after the procedures (see the further description by Frøland and his colleagues [17]). Most participants had little experience with both serious games and entertainment games. The average time for students was one hour, and for teachers, it was 80 minutes, which is mostly attributed to teachers scrutinizing the game's content because of their deeper knowledge of the field. The participants were also asked questions regarding their thoughts and opinions of a VR-version (xStikk) and other applications supporting BLS education, including more immersive simulations or more modalities.

4. Results

4.1. Choosing, Designing, Constructing, and Evaluating Apps and Technologies

Because phlebotomy is an essential competency in BLS education, different supporting learning methods have already been introduced, e.g., web-based information about the process, including snippets of texts with theories or video recordings of the procedures [56]. The next step in supporting learning is to prepare BLS students for training in laboratories, at school, or in practical working places. The aim of developing StikkApp was to bridge theory with practice, not only learning about the phlebotomy process but also demonstrating current tools and forms that professionals need to use at their workplaces.

While there exist several methods of learning phlebotomy, the app used here needed to fit the actual educational and contextual requirements of the BLS environment. Therefore, the educators requested their own app. The freely available mobile apps were not considered usable for the current BLS training due to particularities in the practices for Norwegian students, and therefore, the mStikk mobile app was developed. While supporting 3D virtual environments with devices allowing immersiveness can be beneficial, most of these technologies (e.g., HMDs, HoloLens) are not accessible for everyone. After the construction of mStikk was completed, the mobile app was considered difficult to use in classrooms or in laboratories [16] due to the small screen and difficulty in seeing text and pictures and watching videos. These were the main reasons for asking for a web-based app.

Students and teachers wished to use larger screens during classroom or lab exercises and wanted to integrate some physical, realistic elements via pictures and films. They wanted to have exact copies of some tools and forms (including documents) students or practitioners need to use during phlebotomy. Interestingly, even if the web app was considered useful, our evaluation suggests the need for more realistic experiences that could be provided by virtual reality technologies. A combination of the visual immersion provided by HMDs with haptic input devices allowing the user to experience arms, skin, and equipment better, for example, is in many situations the preferred choice. This is the case for most procedures and skills that are trained for in laboratory practice.

After first evaluating this technology, we then assessed it in context. Regarding Mankins' terminology of the technology readiness level, we decided to go from TRL3 (validation of proof-of-concept) and TRL4 (validation in "laboratory") to TRL5 (validation in relevant environment). As earlier evaluations were not only evaluating the "apps" as results, we were interested in opinions and requirements for other, more supportive apps or utilizing other game technologies. We also investigated which aspects were important to include in the type of game we created and how realistic they had to be.

4.2. Experimental Study

We conducted two testing and development phases of StikkApp, assessing the usefulness of the suggested application. Here, we will detail the results from each of them.

4.2.1. mStikk: User Experiences with Respect to Testing the Phlebotomy Learning Application on Mobiles

The feedback from the evaluations was overwhelmingly positive. The reason for this could be due to students' limited time and experience in labs to test this procedure and a desire to have additional learning methods to maximize their gains from this limited testing time. They considered the application to be something they wished they could have had available when they first learned the procedure. Important factors influencing whether they would use it were its accessibility and the gamification elements making the learning process fun and engaging. Compared to the otherwise mostly passive learning offered by lectures, books, and videos, the interactive nature of the application was an aspect that was highly appreciated. Aside from technical aspects, additional interactivity in the form of animated sections was mentioned as a potential improvement. One of the students who had extensive practical experience at the local hospital disliked the app, considering it "too simplistic". However, even she recognized that this app could be useful, especially for beginner students.

Concerning the usability of the application, the developers learned about the importance of combining different media, e.g., showing videos about the relevant veins and skin colors, the amount of text and theories to connect with the games, the importance of colors with respect to particular objects from the laboratories, etc. It was also essential to adjust the scores in order to make the games more exciting.

4.2.2. wStikk: User Experiences

After testing wStikk, the opinions of teacher users were the most nuanced in relation to providing exact requirements for technical support and also for other procedures that could be supported by SSGs. While the experienced students were initially skeptical about the associated theoretical parts in wStikk, as they "were supposed to know the theories already", they used them frequently, together with supportive videos. The novice students had minimal previous experience with the procedure, and wStikk was mainly their first exposure to it.

Opinions on having both web- and mobile-based learning games were positive from all the participants. Even though the students were unable to test the current functionality on mobile devices, they wished to have apps on both mobile devices and the web, as well as for virtual helmets. Interestingly, this desire to have the option of using different technologies was articulated by teachers as well. However, teachers also expressed their worries about having less than satisfactory technologies and problems with future maintenance.

Teachers voiced a desire to have better solutions for teaching several different processes, with respect to phlebotomy and other issues. They provided examples and possibilities for different methods of training students in phlebotomy and mentioned the challenges of performing this procedure on different types of patient groups, with variables such as age, social problems, and different contexts in which the procedure has to be performed. They also found web applications very suitable to teach other methods, e.g., pipetting or handling a microscope. In Table 1, the authors have summed cumulative experiences from testing wStikk versus other types of applications.

Table 1. Cumulative experiences from testing wStikk versus other types of applications.

	wStikk	Experience Web vs. Mobile vs. Virtual Reality (VR)
Teachers	Very positive, great to activate students during lectures and self-study. Missing: experiences to handle common mistakes, e.g., choosing the wrong type of tube labeling, wrong orders of tubes, and poor hand hygiene. It is desirable to have videos or animations visualizing the consequences of wrong decisions.	The web app is good for self-study and lectures, though the portability of a mobile device is possibly a great advantage. The immersion and possibilities of specialized haptic equipment made VR very interesting, though some skepticism was voiced regarding affordability and knowledge of how to use it. There were concerns regarding updates and support of equipment.
Expert students	Positive towards using the application as supplementary learning opportunities. Wished to initially use the app in the classroom before practicing the procedure. Positive attitudes towards gamification, especially with respect to learning from failures.	Positive towards game-based learning in general. The web version has the advantage of a bigger screen, a mobile device has portability, and VR has immersion and specialized interaction. Regarding when the app is introduced in the educational context, they would appreciate it both at the beginning of the education and additionally as applications available when practicing the procedure later on.
Novice students	Very positive towards this kind of web-based learning. Positive, in general, for technology support.	Some preferred mobile portability while others preferred the bigger screen available for the web version. Positive towards VR if controls are customized, but a bit skeptical regarding lack of portability.

5. Discussion

5.1. Interdisciplinary Initiatives and Technology Support in the BLS Environment

Our experience with the e-learning project of ePraksis suggests that the integration of digital technologies into the learning design of courses is challenging for teachers, even though it is highly desired by students. We considered previous experiences with digitalization (ePraksis) from teachers and educational leaders in this BLS environment as they were willing to try out and find new SSG solutions. The reports from the teachers showed that they are used to being actively involved early in the development and integration of digital solutions. Consequently, they feel they have the competence to contribute when designing new solutions. However, they do not know what is on the market, what is possible, or what needs to be developed.

Many teachers and students have seen serious games applications or “heard about VR, AR, or MR solutions”, usually from daily media. Our observation so far indicates that they highly value the use of digital supporting tools, while at the same time clearly expressing a preference for more technology support to improve learning processes. However, it is important to differentiate which learning scenarios would be merely “nice to have” versus the learning situations that would provide high added value for BLS students’ learning outcome. One takeaway of the collaboration via EduGameLab is that teachers and students would like to have access to all the technologies, but technologies incur costs and their development takes time. Already, considerable time has been spent developing mStikk (BSc work taking up at least 500 h), and the research project developing wStikk lasted approximately six months. It is hard to believe that all needed applications can be discussed in the same way, from identifying learning situations to designing interdisciplinary teams. While we experienced great value gained from the collaboration between BLS teachers, ICT developers, and researchers, together with BLS endusers from clinical hospitals (working life), we have to admit that such cooperation is resource demanding.

A white paper indicating Norwegian perspectives on future trends in biomedical laboratory science [13] indicates that BLS education needs to enhance graduates’ employability skills (e.g., adaptability, problem-solving, and collaboration) through training skills using up-to-date authentic learning approaches and practice-based learning. The new technologies supporting BLS students should thus have authentic learning approaches and practice-based learning as part of their pedagogical framework. Typically, this includes case-based learning, problem-based learning, collaborative learning, scenario-based learning, and role-playing. All these activities may be best supported by different technologies.

Thus, teaching scenarios that can be enhanced by the use of serious games include the following: (i) Roleplaying, for instance, could be useful in guiding the selection of laboratory analyses. Authentic scenarios with roleplaying could be suitable for immersive VR/AR/MR (authentic digital scenarios). Moreover, non-immersive technical solutions could be possible, for example mLearning—as a blended learning tool—training on selecting the correct method for laboratory analyses. (ii) Digital collaborative learning environments influenced by meaningful, digital BLS cases or problems to be solved could be beneficial. Gamification elements and peer assessment can be added to such an environment. Learning situations could, for instance, be used to validate a specific methodology, evaluate the quality of the analyses, or resolve an instrument flag through troubleshooting. (iii) Digital procedural learning to secure procedural skill retention might be effective. One example is the phlebotomy lesson provided by mStikk/wStikk presented in this paper, using mLearning or web learning. Blood specimen collection is a highly relevant, underestimated, and complex procedure in health care.

In our prototype, we focused on teaching the most necessary and basic procedure. There are many other factors that can make phlebotomy challenging for students. Some of these factors are alternative vein selection, proper needle selection, patient posture (bed or chair), patient communication, patients being children, test-specific handling, storage, and transportation requirements, to mention just a few of the scenarios we do not yet cover in mSTIKK/wSTIKK. These challenges were described by the more experienced students testing wStikk. These students did not have a problem with teaching the "normal" or basic procedure, but adding these challenges to the app and to know how to handle these cases would be extremely valuable for them.

Another example of procedural learning is the Hematology Virtual Lab Simulation from Labster, where students learn about the different blood components, how to make peripheral blood smears, how to use an automated blood count analyzer, and how to interpret the results from these experiments. In the virtual laboratory simulation, students experience the typical pipeline of blood samples within one clinical laboratory (hematology). This would also be a suitable approach for following the journey of a patient's samples across various clinical laboratories through the diagnosis process and seeing the final treatment response (a birds-eye view of biological samples in a clinical hospital). Additionally, fundamentally basic laboratory skills across the clinical laboratory disciplines (e.g., micro-pipetting, use of a microscope, use of centrifuge) would also be possible teaching strategies to choose.

5.2. Technology Choice

The goal of the StikkApp project was to assess the applicability of game-based learning on different platforms for use in BLS study programs. The platforms have, until now, been web browsers and mobile phones, but there was also a focus on getting feedback regarding the same type of application for VR headsets. The results indicate that users felt positively towards the use of StikkApp and other similar learning games on several different platforms. The BLS students and educators have themselves pointed out advantages and disadvantages relating to the development of such an app for different platforms. Different grades of mobility, interaction, and immersion all had their advantages and disadvantages. This further reinforces the need to research guidelines for choice of technologies and how to best utilize them in order to maximize engagement and learning potential.

The web application was developed with one of the most important goals being general accessibility, especially for classrooms. The reason for this was based on one of the lessons learned from the development of the mobile application, mStikk, which was considered to be less useful in certain contexts. How to deal with these issues of accessibility and optimization for the different platforms and how they influence learning need to be explored in further studies. The immersive possibilities that VR-based learning games enable were met with great interest, though there is some skepticism towards modifying and updating them. This might also be because of the current lack of such games in the field and lacking experience with customized input and feedback equipment. Based on our findings, further research into serious games for BLS students could be of great value.

While the development process includes a multitude of complex issues, the core focus was always on the application's overall usefulness and discussing how the application, the different functionalities, or the chosen design contributes to the learning goals in focus. Our aim is to create games that the students will use as complementary learning material to other learning methods (in classrooms, laboratories, or elsewhere) in their education, at the same time learning from StikkApp to construct other applications.

5.3. Scaling up

A major challenge for the use of SSGs in education lies in scaling up its use. There is a seemingly easier possibility of incorporating existing SSGs from the market. However, this is rarely an optimal solution as existing environments are generally unable to procure and use digital solutions without adapting these to their own education, even if these digital solutions may show benefits for other situations. Acquiring SSGs, applying the necessary adjustments and assuring quality and correctness through testing is often costly. These environments rarely have the resources for this. While IT-departments or media support at the universities can help with procurement or startup, they cannot guarantee continued help with updates, or replacements, even if the solutions are freely available. Thus, at an organizational level, a gap currently exists with respect to digital environments that explore ways to create and implement cost-effective SSG solutions for BLS education. This also includes strategies for how to adapt learning games to local conditions. Even if we have several successful environments and groups supporting BLS education, there is not a complete package and methodology describing how these successful environments could be taken over by another environment [44].

On the other hand, if one is to develop new games as part of an SSG environment, there is a challenge in how to define more games. A critical step for this is to identify which learning situations are suitable. As the involvement of both teachers and students is something we think of as critical in this endeavor, we propose as a first step to defining more games, the participation of students, teachers, and BLS program graduates engaged in working life in a design thinking workshop to explore their ideas and requirements. This is in accordance with guideline recommendation 7 of Tsekleves et al., which suggests a co-design process with stakeholders [11]. As a follow-up to the results of such a workshop, we recommend an exploration of existing solutions and a discussion of the future usability of the suggested serious games and the specific learning situations. To maximize the returns from these efforts, one should explore the possibility of reusing and repurposing parts of the framework of the game(s) to other learning situations or study programs.

While a local SSG environment may have the competence for the development of novel educational technology, there are challenges in ensuring the sustainability of such games and expanding into multiple SSGs. One solution is to expand the environment from a local initiative to an international collaborative project in order to share pedagogical knowledge and practices to further develop and explore digital technologies and prototypes.

To provide additional value from their local initiatives, institutions should share results and experiences from their development of educational games with other BLS educators in the form of a database of serious games (establishing a learning initiative network) while also including the experiences of individual educators regarding implementing the technology within the learning design of their courses. This would also include gathering the opinions and experiences of students regarding the games and trying to include them in the development and integration work. This concept could be important for knowledge sharing and hence a tool to empower BLS teachers to transform their teaching practices.

An additional strategy would be to make a larger interprofessional impact within one's own institution through SSG initiatives. However, it is often challenging to achieve such strategic goals, with the responsibility often being laid upon the teachers. This tends to lead to initiatives made by a few highly committed and motivated teachers while the rest of the institution stays at a standstill. If SSG environments are to make an impact locally, they should act as an integral part of a pedagogical support unit. Such a support unit could ensure a reuse/repurposing of prototypes to other educational programs, bringing a holistic view and guiding the integration of SSGs into education. Some of the questions that arise from this would be how and when should one utilize the solution, and how can knowledge be transferred from one educational program to another? An SSG environment as an advisory group could work with educational leaders to create a framework for an actionable plan for digitalization of education; a framework in which the teachers and educational leaders must involve themselves and as such facilitate commitment—a commitment to alter educational practice (a top-down–bottom-up process).

6. Future Work

From the testing of wStikk and mStikk, we uncovered a great interest in different kinds of technological solutions, in particular VR. We asked our participants questions with two main areas of focus: (i) adoption of the tested technology and (ii) how to maximize the learning outcome.

As can be seen from Table 1, there were two critically important aspects mentioned regarding the (i) adoption of VR-based solutions:

(1) A need to support the initial adoption phase, including economic cost and knowledge of how to use the solution.
(2) A plan for how the solution is to be updated and supported.

These findings demonstrate the necessity of having an appropriate support structure present when adopting new technologies in education, in accordance with Wouters and his colleagues [9], and managing issues related to the sustainability of solutions [7]. With regard to the economic aspect (1), a VR lab at the campus was thought of as the most feasible solution given the current cost of suitable equipment. At the same time, an interdisciplinary group was believed to be the right approach for (1) providing initial knowledge of how to use the solution and (2) providing continued updates and support.

Regarding how to (ii) maximize the learning outcome, we let the participants provide an overview of where they felt the different technologies fit in. From our current results, there is no clear solution that fits all users. The participants' views of the technologies and where VR fits in were as follows:

- Applications for mobile phones have the advantage of being portable, which makes it possible to practice the material in many situations, such as when taking a bus. They consider it very suitable as a complementary solution.
- Web games, on the other hand, achieve a bit more immersion and can make it easier to cooperate with others and integrate the technology into teaching situations, at the expense of reduced portability.
- Utilizing technologies such as VR and AR allows for more immersive experiences that can heighten the learning outcome if appropriately done, but this strategy is generally more expensive.

As such, there are unique advantages and disadvantages for each technology. An aspect that most of the participants mentioned as a way of enhancing the VR experience was an exploration of specialized haptic equipment to bridge the gap between the virtual and real world. To be able to touch and interact with input devices that closely resemble real equipment was believed to have a greater immersive and learning effect. This could be a pivotal aspect to take into consideration when developing AR and VR solutions for learning practical skills. Minimizing the differences between the training situation and the real situation can result in a more significant transfer of practical skills. Additionally, providing gamified elements and feedback directly in the context of the practical procedure and equipment could also enhance the learning and retention of theoretical knowledge. Further exploring these opportunities, a haptically centered input scheme in combination with the immersive visual technologies of VR and AR HMDs could be a promising solution.

The participants also discussed suitable learning outcomes for the use of VR. The areas that were perceived as the best candidates involved a combination of hands-on procedures with visual analysis and assessment. Practicing the skills in a virtual environment similar to an actual working environment was seen as positive. Some of the mentioned procedures are presented below:

- Pipetting;
- Use of microscope;
- Blood culture testing;
- Capillary blood sampling.

7. Conclusions

The overall aim of this paper was to contribute to discussing the need for and contribution of digital solutions to learning procedural skills. This was done by following the design and development of StikkApp as part of the overarching EduGameLab initiative and discussing ways to deliver engaging and interactive learning content to teachers and students in the BLS field. By developing and testing for different platforms, we have uncovered opportunities and challenges in implementing SSGs for BLS education.

The results showed that there is great interest in SSGs for BLS education among the participants. Mobile, web, and VR platforms all had interesting benefits and trade-offs; thus, a suite of games was suggested. The accessibility of mobile applications, the immersion of VR, and the middle ground of web applications were highlighted. A potential VR application should utilize specialized haptic input methods to allow for training in hand-based skills.

This paper shows not only the construction of SSGs but also the experiences and opinions of academics, practitioners, and students in the development of digital tools that support learning. We also show the potential of StikkApp and similar games to expand into covering other procedures and learning scenarios for BLS and other fields. Ways of utilizing different digital technologies to create a compelling suite of games for students and educators were discussed. However, developing and testing games takes time and resources. To further develop games to be more sophisticated, e.g., include special cases, would require support from other environments.

Regarding the challenges in BLS education with not only limited resources and time at campus, but also in supervised professional placement fields, we see that SSGs do not necessarily give more time and resources. However, they can contribute to transforming teaching and learning in such a way as to advance teachers' ability to deliver more effective education. Because the use of digitalization can support active student learning, educators have learned to plan for ICT pedagogy and are willing to incorporate these plans to use SSGs such as mStikk/wStikk.

A significant challenge for BLS education lies in how to reproduce the up-to-date conditions (or elements of the conditions) of an authentic working environment on campus. In our work, it was possible to explore continuously, together with BLS students and BLS professionals from working life, authentic learning situations for making the prototypes of m-/wStikk. This ensured that the elements of an optimal authentic working environment were as realistic as possible. However, these user experiences need to be considered carefully due to missing (not yet finished) tests in classrooms.

A final observation is that SSGs address issues that may have an impact on the overall BLS study program content, learning design/structure, and resource management. Accordingly, we hope our recommendations for the support of serious games can help advance others' ability to deliver effective education for students. A broad program of change cannot be implemented overnight. Now is the time for faculty leadership to begin addressing these issues. We need new organizational strategies to ensure better support, internal communication, and coordination of serious games resources at universities. Furthermore, institutions should take measures to catalyze or support long-term interdisciplinary capacity building within educational innovation.

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