Review

3D Immersive Patient Simulators and Their Impact on Learning Success: A Thematic Review

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Abstract

Background: Immersive patient simulators (IPSs) combine the simulation of virtual patients with a three-dimensional (3D) environment and, thus, allow an illusionary immersion into a synthetic world, similar to computer games. Playful learning in a 3D environment is motivating and allows repetitive training and internalization of medical workflows (ie, procedural knowledge) without compromising real patients. The impact of this innovative educational concept on learning success requires review of feasibility and validity.

Objective: It was the aim of this paper to conduct a survey of all immersive patient simulators currently available. In addition, we address the question of whether the use of these simulators has an impact on knowledge gain by summarizing the existing validation studies.

Methods: A systematic literature search via PubMed was performed using predefined inclusion criteria (ie, virtual worlds, focus on education of medical students, validation testing) to identify all available simulators. Validation testing was defined as the primary end point.

Results: There are currently 13 immersive patient simulators available. Of these, 9 are Web-based simulators and represent feasibility studies. None of these simulators are used routinely for student education. The workstation-based simulators are commercially driven and show a higher quality in terms of graphical quality and/or data content. Out of the studies, 1 showed a positive correlation between simulated content and real content (ie, content validity). There was a positive correlation between the outcome of simulator training and alternative training methods (ie, concordance validity), and a positive coherence between measured outcome and future professional attitude and performance (ie, predictive validity).

Conclusions: IPSs can promote learning and consolidation of procedural knowledge. The use of immersive patient simulators is still marginal, and technical and educational approaches are heterogeneous. Academic-driven IPSs could possibly enhance the content quality, improve the validity level, and make this educational concept accessible to all medical students.

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KEYWORDS
immersive patient simulators; Web-based learning; validity; immersion; procedural knowledge
Introduction

One key factor of clinical education is the transfer of declarative knowledge (ie, “what to do”) into procedural knowledge (ie, “how to do”). It is performed most effectively in small groups accompanied by a medical teacher [1]. However, in the daily practice clinical instruction is often based on a traditional apprenticeship process and on the expectation that if a student spends enough time in a clinical environment he or she will eventually “get it”. Although this education is good clinical practice and known to be successful, it is impaired by increasing workload of hospital doctors, restrictive working time directives, and changes of students’ attitudes and expectations in the sense of the Generation Y [2]. Therefore, new educational strategies (eg, skills labs or mannequin simulators) are developed [3,4]. Virtual patient simulators go one step further as they allow case-based learning on personal computers. In a blended learning context they can have a positive impact on knowledge gain [5]. The available simulators vary greatly in realism and interaction grade, however it is questionable whether this factor affects learners’ outcome. Technological advances have allowed virtual patient simulators, such as immersive patient simulators (IPSs), with a high level of realism and interaction grade similar to computer games (ie, serious games). IPSs must not necessarily be installed on the user’s home computer (ie, workstation based). New technologies enable streaming of even complex programs via the Internet directly into the user’s browser (ie, Web-based).

Figure 1. Example of a 3D virtual environment streamed via the Internet directly onto the learner’s computer (ie, Web-based) where the user can freely walk around and interact with the environment—authors’ project in collaboration with Clemson University, SC, USA.

Methods

A systematic search of literature via PubMed of articles from 1986 to 2014 on IPSs was performed with a focus on education of medical students. IPSs were defined as digital environments that simulate medical workflows and show the characteristics of real-time simulation with free interaction in a 3D setting. As browser technology is developing fast, not only workstation-based simulators, but also Web-based simulators were included. Simulation of one-step procedures (ie, intubation, puncturing) were excluded. Search terms included a combination of “simulation,” “virtual reality,” or “virtual worlds,” and “education” or “training.” Peer-reviewed publications from 1986 until 2014 were included. Eligibility assessment was performed independently by two reviewers and disagreements between reviewers were resolved by consensus with a third reviewer. Titles and abstracts of all articles were screened with regard to relevance and consequently grouped—relevant articles and articles of unknown relevance were screened in full text.
Furthermore, reference lists of relevant articles were searched for additional articles that were possibly not identified until then. Identified immersive patient simulators were classified by the field of application, technical parameters (ie, Web or workstation based, immersion grade, features), medical content (low ≤3 cases, medium = 4 to 8 cases, high ≥9 cases), and existing validation studies.

Validation was assessed according to the consensus guidelines for validation of virtual reality surgical simulators [6]: (1) concordance (aka, face) validity refers to the degree of resemblance between simulator training and training in reality, (2) content validity refers to the degree to which simulated content covers the dimension of the construct it aims to educate, (3) construct (aka, contrast) validity describes the impact of existing knowledge on simulator performance, and (4) predictive validity describes the simulator impact on future performance applications [7,8]. Validation studies were further classified in accordance with the Cochrane Handbook for Systematic Reviews of Interventions. Studies were parameterized by methodical aspects (ie, study design, level of content), technical details of the IPS, end points, and study results. Validity of observational studies was assessed by using the methodological index for nonrandomized studies [9]. Literature review and data extraction was performed by two reviewers independently, and compared afterwards.

**Results**

**Overview**

The systematic literature search (Figure 2) identified 16,946 publications that matched the criteria.

A total of 13 publications were identified as relevant in terms of describing the use of virtual worlds in medical education (Table 1). Of these publications, 9 described IPSs that were Web-based and 4 described IPSs that were workstation based.

### Table 1. List of available virtual patient simulators.

<table>
<thead>
<tr>
<th>Virtual world</th>
<th>Type</th>
<th>Content</th>
<th>Immersion</th>
<th>Content level</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>VNEC</td>
<td>WBᵃ</td>
<td>Neurological disorders</td>
<td>Medium</td>
<td>Medium</td>
<td>[10]</td>
</tr>
<tr>
<td>Play2Train</td>
<td>WB</td>
<td>Emergency medicine</td>
<td>Medium</td>
<td>Medium</td>
<td>[11]</td>
</tr>
<tr>
<td>MeRiTS</td>
<td>WB</td>
<td>Emergency medicine</td>
<td>Medium</td>
<td>Low</td>
<td>[12]</td>
</tr>
<tr>
<td>Second Health London</td>
<td>WB</td>
<td>Emergency medicine</td>
<td>Medium</td>
<td>Medium</td>
<td>[13]</td>
</tr>
<tr>
<td>CliniSpace</td>
<td>WB</td>
<td>Emergency medicine</td>
<td>Very high</td>
<td>High</td>
<td>[14]</td>
</tr>
<tr>
<td>Pulse</td>
<td>WB</td>
<td>Emergency medicine</td>
<td>High</td>
<td>High</td>
<td>[15]</td>
</tr>
<tr>
<td>3D Emergency Department</td>
<td>WB</td>
<td>Emergency medicine</td>
<td>Medium</td>
<td>High</td>
<td>[16]</td>
</tr>
<tr>
<td>Inmmedea</td>
<td>WB</td>
<td>Various clinical cases</td>
<td>Low</td>
<td>High</td>
<td>[17]</td>
</tr>
<tr>
<td>Olive</td>
<td>WB</td>
<td>Emergency medicine</td>
<td>Medium</td>
<td>Low</td>
<td>[18]</td>
</tr>
<tr>
<td>Project TOUCH</td>
<td>CBᵇ</td>
<td>Various clinical cases</td>
<td>High</td>
<td>Medium</td>
<td>[19]</td>
</tr>
<tr>
<td>Virtual Emergency Department</td>
<td>CB</td>
<td>Emergency medicine</td>
<td>High</td>
<td>High</td>
<td>[20]</td>
</tr>
<tr>
<td>TriageTrainer</td>
<td>CB</td>
<td>Triage</td>
<td>High</td>
<td>Low</td>
<td>[21]</td>
</tr>
<tr>
<td>Burn Center</td>
<td>CB</td>
<td>Burn wounds</td>
<td>High</td>
<td>Medium</td>
<td>[22]</td>
</tr>
</tbody>
</table>

ᵃWeb-based (WB).
ᵇComputer-based (CB) (aka, workstation based).
Web-Based Simulators

Out of 9 Web-based IPSs, 5 of them use the 3D technology of the widely used social network, Second Life (SL). All of these 5 IPSs were developed by university groups. None of these IPSs are routinely used in the education of medical students or medical staff, as they are technical feasibility projects with general medical content and focus on medical knowledge exchange [11]. However, they show the technical feasibility of providing medical education via virtual worlds [10]. A total of 3 of the Second Life-embedded virtual worlds were designed for team-based training in medical education—Second Health London is provided by the Imperial College London and was used in a pilot feasibility study including a first validation [13]. MeRiTS also offers team-based training in an SL environment, which was summarized in a feasibility study [12] without validation so far. Due to the technical specifications of Second Life, the graphical quality is not state of the art. This limitation potentially influences learners’ immersion, as graphical quality and presentation have an effect on immersion grade [23].

Web-based simulators are comparable to SL simulators, however, the main difference is the technical background. Web-based simulators use a proprietary 3D engine program, which makes development of 3D worlds more resource intensive, but enables more possibilities in graphical quality and custom program design. Of the 4 remaining Web-based IPSs, 1 was already presented in 2003 and uses a custom-made 3D world. Again, the key aspect of the simulator is a feasibility study, in this case particularly with regard to distance learning [19,24]. The 3 remaining Web-based IPSs were built by commercial software companies. Of these, 2 of them show a high 3D graphical quality and, thus, a high immersion grade. They offer team- and case-based training of acute clinical cases, with the main focus on emergency medicine [14]. The high quality is reflected by the elevated pricing of these simulations—more than US $5000 for a 1-year subscription. The medical content is high and custom-made virtual cases can be added for an additional fee. The CliniSpace IPS has already been used by Stanford University for emergency procedure training in the trauma room [16,20]. The remaining IPS,
Inmedea, offers low immersion as it does not use a 3D engine, but consists of freeze-frames with drawn graphics. However, the amount of medical content in this simulator is very high, and custom cases can also be added when necessary. Although it is commercially driven, there are several universities that already use this simulator in a blended learning concept [25,26], and there are already first validation studies [17].

**Workstation-Based Simulators**

Workstation-based IPSs need to be installed on a computer and offer high immersion with high-fidelity 3D graphics, as they are not limited by the technical handicaps of Internet broadcasting. Out of the 4 simulators, 3 of them are still undergoing feasibility studies, as they were not already validated for their effectiveness [22,27]. Although 1 of the simulators was introduced 10 years ago, it is neither routinely used in student education, nor has it been validated yet [19]. The remaining commercial VW environments by the University of Birmingham offer training in triage casualties in a simulated live exercise [21], which was part of the first validation study.

**Validation**

The literature search uncovered 5 articles that included validation studies, however, no study assessed all levels of validity. One of the available VW simulators validated the coherence between simulated content and real content (ie, content validity) in training of emergency procedures [13]. The correlation between the outcome of simulator training and alternative training methods was proved in 2 virtual worlds [16,20] (ie, concordance validity)—in all 3 validation studies, simulator training was comparable to alternative training in terms of outcome. The coherence between measured outcome and future performance (ie, predictive validity) was validated in 2 simulators [21,17] and showed a positive correlation. The simulators and corresponding validation studies are summarized in Table 2.

**Table 2.** Overview of the validity level of all currently available virtual patient simulators.

<table>
<thead>
<tr>
<th>Validity type and study</th>
<th>Number of participants</th>
<th>Virtual world</th>
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</thead>
<tbody>
<tr>
<td>Content validity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concordance validity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LeRoy Heinrichs et al, 2008</td>
<td>30</td>
<td>3D Emergency Department</td>
<td>[16]</td>
</tr>
<tr>
<td>Youngblood et al, 2008</td>
<td>30</td>
<td>Virtual Emergency Department</td>
<td>[20]</td>
</tr>
<tr>
<td>Predictive validity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Funke et al, 2012</td>
<td>116</td>
<td>Inmedea</td>
<td>[17]</td>
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<tr>
<td>Knight et al, 2010</td>
<td>91</td>
<td>Triage Trainer</td>
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**Discussion**

**Principal Findings**

This paper gives an overview of the available IPSs and corresponding validation studies and, therefore, summarizes the current situation in learning in virtual worlds. Previous studies revealed that using virtual patient simulators can have a positive impact on learning success [5], whereas the effect of realism grade on knowledge gain is still under discussion. IPSs as a subgroup of virtual patient simulators offer high interaction grade and realism as in computer games (ie, serious games). However, we intentionally separated the group of immersive patient simulators from serious games, as the focus of these simulators lies more on knowledge transfer than on classical game elements. The potential of IPSs lies in the internalization of diagnostic and therapeutic procedures, such as resuscitation or diagnosis patterns. Ideally, the underlying procedures are already predefined to achieve performance uniformity, similarly to standard operating procedures in the clinical daily routine [28]. It is known that immersion plays a fundamental role in virtual reality simulators, as identification with the avatar influences motivation and improves learning success [23]. However, immersion grade is influenced by many factors [29] and, therefore, hard to verify. A study from 1999 revealed that “there were no statistical differences in presence or reality judgment between a high-impact workstation and a PC workstation” [30]. However, this study was conducted before the high-fidelity graphic era and the results are not entirely transferable, as the high-impact workstation (Silicon Graphics) from 1999 was still far away from the 3D capabilities of current standard personal computers, and realism grade was comparably poor. Furthermore, the majority of the students were not used to computer worlds and, thus, less susceptible to learning with 3D worlds. Newer studies revealed that there was a positive impact of high-fidelity visual presentation on degree of immersion [31] and even on learning performance [23]. For clinical teachers, the question arises whether IPSs can support the daily routine and have an effect on students’ future performance. Assessment of new educational concepts includes different forms of validity. Content validity describes the correlation between simulated and real content. There was a positive correlation between simulated content and real content (ie, content validity) in training of emergency procedures [13]. The correlation between the outcome of simulator training and alternative training methods was proved in 2 virtual worlds [16,20] (ie, concordance validity)—in all 3 validation studies, simulator training was comparable to alternative training in terms of outcome. The coherence between measured outcome and future performance (ie, predictive validity) was validated in 2 simulators [21,17] and showed a positive correlation. The simulators and corresponding validation studies are summarized in Table 2.

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knowledge level by the participating students. Verification of predictive validity illustrates that there is an impact of learning with IPSs on future performance, and consequently enables successful preparation for hands-on training [17, 21]. However, all current IPSs are used in the blended learning context, as postprocedural review of students’ performance immediately after training is known to be essential for an adequate knowledge gain [32]. Moreover, there is evidence that preexisting knowledge has a positive impact on simulator performance (i.e., construct validity), although the group size of this study was low [13]. None of the articles assessed all forms of validity. As the studies are heterogeneous in medical content, the number of participants, and types of simulators, the initial question of whether the use of IPSs in the daily curriculum is beneficial in terms of learning success cannot be fully answered at this time. However, validation of single parameters revealed that IPSs can potentially support clinical teaching, although teachers must be aware of the limitations. IPSs are limited in terms of teaching declarative and procedural knowledge. Clinical education is not limited to teaching standard operating procedures, but is furthermore characterized by weighing clinical findings, evaluation of different hypotheses, and clinical experience. Therefore, IPSs are not intended to replace clinical teachers, but should support young students without relevant clinical experience. Regarding content, currently available virtual reality patient simulators range from small procedures, such as triage training, to complex procedures, such as emergency room protocols, up to teamwork with user-user interaction. The more complex the simulation, the more resources are needed. Therefore, it is not surprising that the complex simulations are commercially driven. Academic teachers can rent these simulators, making them more cost-effective, but it is questionable whether the development of a teaching method should be delegated. A highly immersive, multituser, virtual reality simulator developed and supervised by an expert team of academic teachers would potentially allow, not only that the multiple users would train on one case (i.e., team play), but also that one student would train on more than one patient at a time (i.e., multitasking). These nontechnical skills can hardly be taught in reality, but are recognized as potential risk factors in high-risk environments like the emergency room or operating room [33]. It is the responsibility of universities and teaching hospitals to enable teaching methods that improve patient safety, reduce errors, and to further validate these new teaching methods.

Conclusions

Immersion patient simulators can potentially promote learning and consolidation of procedural knowledge. Web-based simulators allow time- and location-independent learning at an individual pace. The use of immersive patient simulators is still marginal, and technical and educational approaches are heterogeneous. Academic-driven IPSs could possibly enhance the content quality, improve the validity level, and make this educational concept accessible to all medical students. The development and validation of such a simulator will be the subject of our future research.

Conflicts of Interest
None declared.

References


Abbreviations

3D: three-dimensional
IPS: immersive patient simulator
SL: Second Life
VW: virtual world