Rapid Development of Game-like Interactive Simulations for Learning Clinical Procedures

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ABSTRACT
Traditionally, medical education has used live patients to teach medical procedures. This carries a significant risk to patients. . As learning technology advances, the early integration of computer-aided medical simulations into medical training before patient contact is becoming an ethical imperative, yet development costs are constraining. In this paper we describe the use of a gaming engine to rapidly create a game-like interactive simulation for medical training at a low cost. Our process model, driven by the simulation storyboard provided by the instructors, allows for easy simulation refinements and permits an early evaluation of the educational outcome. We also describe its initial integration into the existing matrix of low-tech simulation (procedures practiced on mannequins) and a high-tech educational platform (e-learning system) used to support and track novice physicians within a large academic training center.

Categories and Subject Descriptors
K.3.1 [**Computers and Education**]: Computer uses in education - *Collaborative learning, Computer-Assisted Instruction (CAI), Computer-Managed Instruction (CMI), distance learning.*

K.6.3 [**Management of Computing and Information Systems**]: Software Management - *software development, software maintenance, software process*

J.3 [**Life and Medical Sciences**]: Health.

General Terms
Management, Measurement, Design, Standardization

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Keywords
games, simulations, medical training, serious games

1. INTRODUCTION
Over thousands of years, medical education has relied on a master-apprentice system where patients are the primary learning tool for first-time medical procedures. This has created an ethical tension between the need to hone the skills of health professionals on live patients while insuring patient safety and well-being [30]. The emergence of high-powered computing, which allows real-time virtual interaction with haptics, is putting us in a position where we can mitigate this ethical tension by developing healthcare workers' skills early on by using realistic patient simulators without putting patients at risk. While this kind of advanced simulation technology may allay this tension, it also introduces a new dilemma concerning the development cost of highly advanced computer-driven simulators and their integration into existing educational infrastructure.

Following the taxonomy of medical simulations from [30], an alternate approach, which provides the realism necessary to develop motor skills is the use of Virtual Reality (VR) environments with realistic haptics. However, the current costs of developing these virtual reality environments are also prohibitive unless they are generic enough to be broadly applicable and to provide reasonable amortization.

However, when dealing with specific procedures of limited application, computer-based educational games and game-like simulations can offer advantages over other forms of training (e.g., practice exercises using mannequins or live patients), allowing a broader range of experimentation, feedback and reflection on mistakes. Game-like simulations can be played by the trainees at home, as many times as desired and at their own pace. They are free to explore, to try different approaches, without fear of breaking the equipment and, potentially, with the guidance and feedback provided by the simulation itself.

Motor skills are often only a small part of what needs to be honed when learning to do a procedure. Most procedures require a combination of motor skills and the memorization of a large number of steps required before, during, and after the procedure. Learning with game-like simulations can provide important prior knowledge, so that motor-skill training and face-to-face exchange can be the focus when practicing the procedure in the presence of a clinical educator. This can reduce the total face-to-face time needed, increase the value of the teaching encounter, and ultimately reduce the risk involved in training on live patients.

Additionally, in order to coexist with the modern technology-enhanced learning settings, educational games and game-like simulations cannot be independent artifacts, but must be integrated with co-existing courses and training modules. Take for example, *The Hub*, a community-driven learning and knowledge management system, which is used by physicians in the Internal Medicine training program at the Massachusetts General Hospital (MGH). *The Hub* is built on top of the opensource .LRN e-learning platform [4], with several training courses already deployed there. The community value and the results achieved through *The Hub* encourage us to seek new applications of these technologies and the educational games and simulations used in training should not be disconnected from these environments. On the one hand, it should be possible to launch the games from within the online training environment, just as if they were a document or a streamed video. On the other hand, the game should monitor automatically the performance of the student, measuring the time required to complete each task, committed errors and level of completion. Finally, the data gathered from the monitoring of the student should be available as a report for the instructors as well as an automatically generated grade to be stored with the student's profile and achievements.

This work describes a design and implementation methodology for medical simulations that avoids the high development costs of VR-like simulations, and successfully addresses the integration requirements with the existing e-learning platforms (in particular, those identified in the context of *The Hub*, although the results apply for other training platforms). For this purpose we conceive simulations as game-based modules and we use <e-Adventure>, an educational game engine created at Complutense University of Madrid for their implementation. The tool provides an economical pathway to rapid prototyping of game-like simulation environments with the direct involvement of instructors so that the educational value can be evaluated early and future investment and development direction can be better gauged and planned.

The rest of the paper is organized as follows. In section 2 we present the design and implementation methodology. In section 3 we illustrate it with a case study. Finally, in section 4 we discuss the conclusions derived from this work, as well as some lines of future work.

2. THE DESIGN AND IMPLEMENTATION METHODOLOGY

Clinical practices do not only rely on an appropriate training of the motor skills or tactile tasks, but also require the memorization of a large number of related steps required before, during, and after the procedure. For this purpose we propose a blended-learning approach, where a simulation can be used to get an overview of complex procedures and the additional skills required can later be exercised in focused practical sessions. In our approach simulations are conceived as *point-and-click adventure videogames*. Adventure videogames have been already identified as a suitable game genre for education [2, 15, 29], especially when it comes to learning complex procedures that involve sequences of steps. The phases we defined to create a simulation for an already established clinical procedure involve formalizing the steps (writing them down in full detail), turning them into storyboard, implementing the simulation and then integrating the product into the rest of the training program. The following subsections detail each of these phases..

2.1 Conception of the Storyboard

When creating a simulation for a clinical procedure, ideally the creation of the initial storyboard is performed by the same physicians responsible for the training program. Typically, clinical procedures take place in a number of locations. A procedure could involve, for example, some activities in the patient's room, a visit to the lab to get some results, and checking with the nursing station for updates. The storyboard should include descriptions of all these locations.

Additionally, other participants in the procedure (patients, nurses, etc.) populate the diverse locations. Those participants are described as characters that the trainee can interact with during the execution. Also the procedures involve interacting with objects, which should also be described in the storyboard.

Finally, as described in [23], a network of scenarios that can simply be navigated and where every object and character always says or does the same things does not create a meaningful game-like simulation. The procedures have steps and possible branches depending on certain conditions (e.g., "Is the patient conscious? "What are the test results?"). That is to say, the simulation must include a notion of state, and performing a specific activity within the simulation usually requires having performed some other activities first. Thus, the storyboard should contemplate steps, which are sequenced, and include branches that may have an effect on what should be done next.

2.2 Planning the Monitoring and Assessment

One of the most important requirements identified in our experiences with technology-enhanced learning is the need to monitor and assess the performance of the learners who interact with the different learning artifacts. Indeed, we identify it as a primary requirement for integrating simulations in the context of *The Hub*, and we consider that it deserves a distinctive phase in our methodology. For this purpose, once the storyboard is ready, the instructor also prepares documentation describing the evaluation profiles. Since we want to monitor the performance of the student, it is necessary to identify what constitutes "good performance".

The assessment plan should cover the objectives that the formalized procedures try to accomplish. Questions that should be answered include "which steps are critical in the procedure?", "which branching decisions are correct?", and "what final states in the procedure are considered a success?". Using this plan, it could be possible to define rules that will transform the path followed by the trainee into a final grade and a written report with feedback purposes.

2.3 Implementation of the storyboard

Once a detailed storyboard is available, the next step is to choose an appropriate technology for its implementation, with special attention to cost-effectiveness. Since these game-like simulations are only used to support part of the training (i.e., they do not substitute for the rest of the training program) the cost is definitely an issue. For this purpose we propose to use our <e-Adventure> platform.

The opensource <e-Adventure> platform was originally developed for the creation and execution of educational adventure games with modest technical requirements at a low cost. We found the engine covered most of the requisites outlined in the previous section, such as efficient involvement of the instructor physicians, while the cost-efficiency of the development process provided by the platform was ideal.

Additionally, <e-Adventure> uses an XML (*eXtensible Markup Language*) notation [3, 5] to describe the games that are interpreted by the engine and offers an authoring approach that facilitates the transition from the storyboard to a running game. Indeed, the alluded XML notation is a domain-specific markup language [28] that formalizes the typical structure of storyboards for adventure videogames. This helps us guarantee that no vital information is lost in the process of implementing the script. Indeed, as described in [24], the center of the entire implementation process is the actual storyboard. The platform also includes a simplified XML editor that facilitates this process.

2.4 Implementation of the monitoring and assessment plan

Regarding the monitoring and assessment of the performance of the trainee during the simulation, <e-Adventure> includes a built-in assessment mechanism that supports the objectives related to monitoring and reporting the activity of the learner [23].

The configuration of this mechanism is also performed using either XML files or the supplied graphical editor, which means it should be straightforward to use it to implement the assessment profiles that are created during the planning of the assessment.

2.5 Gathering and integrating the art assets

Often one of the most costly aspects of game and simulation development is obtaining the art assets that will be included with the game, as well as integrating these assets in the final videogame. Again, we focused on developing a sustainable methodology with a low cost.

Given that these procedures are being taught in the context of a healthcare institution, we used actual photographs of the environment in which the procedures take place and the items employed. We found that one of the cheapest and most effective ways of modeling a patient's room was to take a photo of that room.

We hope the use of photorealistic environment will help familiarize trainees (often recently arrived residents) with their workplace. If the simulation requires going to the nursing station to check some information and this action is performed by navigating a series of pictures of the actual hallways, the trainee will find it easier to find the station when working on the medical wards depicted.

The <e-Adventure> platform clearly separates the treatment of the script from the treatment of the art assets, which facilitates both processes. It is possible to implement the script while the assets are gathered and then it is a straightforward process to include the assets in the simulation by using the supplied editor.

2.6 Deployment as part of a training program

Finally, <e-Adventure> is designed with the purpose that the educational games produced are easily integrated with online learning environments compliant to the IMS Learning Design (IMS LD) specification [13, 16]. IMS LD, which is currently supported by the .LRN platform that powers the online educational platform, currently in use by the Department of Medicine at the Massachusetts General Hospital (MGH) [9].

The IMS LD specification allows the formalization of complex instructional designs including collaborative activities, branching and adaptive learning [6] and is currently considered the reference specification for educational modeling [10]. This means that the simulations can be launched from a web environment and that the engine can push the reports and the grades obtained within the simulation to the profiles of the learners.

The simulations are launched as a Java Applet from the learning environment along with the rest of the learning materials. Then the assessment mechanism built into the engine pushes the assessment information (grades and reports) to the learning environment as the trainee executes the simulation [20].

The latest scores achieved by each trainee are stored in the environment along with their results from other tests of their training program. In addition to the final score, the engine also generates human-readable reports explaining all the criteria included in the final score. These documents are shown to the trainees so that they receive feedback about the mistakes made and are also available for the instructors so that they can see where the trainees are failing and act accordingly.

3. CASE STUDY: IMPLEMENTING A SIMULATION OF THE CVC INSERTION PROTOCOL

In the Blake-7 Medical Intensive Care Unit of the MGH there is an ongoing effort to reduce the number of cases of central line infection. For this purpose, there is a formalized 98-step protocol for the Insertion Procedure of Central Venous Catheters (CVC) [12]. This type of catheterization is a delicate procedure, involving the insertion of 20 to 30 cm of wire into the patient's chest, in order to drive the tip of the catheter right to the junction of the Superior Vena Cava and the heart's right atrium, accessed via either the Jugular vein or the Subclavian vein.

The protocol's main aim is to improve the quality of the sterile technique during the procedure. Since central line infections are potentially fatal, following this protocol closely is a necessary requirement. However, the residents being trained at the Medical Intensive Care Unit (ICU) find it hard to remember all the steps, especially when working under the additional pressure they experience the first few times that they perform this aggressive procedure.

For this reason, there are ongoing training sessions using specially designed mannequins. These mannequins have the corresponding

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anatomical landmarks that allow the localisation of the targeted landmarks and emulate the texture and anatomy of real tissue.

During these sessions, one or two residents start the CVC protocol guided by an experienced physician (the clinical educator), who takes notes on trainee performance.

However, these sessions take longer than they should, making it hard to find enough time to perform them as frequently as desirable. Additionally, the feedback gathered from the residents after the training sessions suggests that the procedure itself is not as difficult for them as following all the preparatory steps required by the protocol.

Thus, we decided to create a game-like simulation in which the trainees could go through all the steps of the protocol, trying to complete the procedure against the clock and with competitive results being posted online.

It must be noted that having a simulation of this procedure cannot substitute for the training sessions with mannequins (let alone with live patients) due to the lack of tactile feedback and the fact that the trainee is not really practicing the landmark localisation and the actual movements during the procedure.

However, having a simulation of this 98-step protocol helps the trainee practice and memorize the reaquired steps so that they are well prepared for sessions with an instructor.

This approach should save on-site instruction time and increase the confidence of the residents when performing the procedure with live patients.

Next we describe how our design and implementation approach has been applied in the development of the mentioned simulation.

3.1 Conception of the Storyboard

The game starts with the trainee standing in the corridor of the Blake-7 Medical ICU at the MGH. From here, the first step is to proceed to the actual location of the supply room to gather the supplies required for the procedure (except for those already available in the patient's room).

Fig. 1. During parts of the procedure, the bed should be in Trendelenberg (head down) position in order to facilitate vessel engorgement and optimize conditions for the procedure. The controls for the bed are the same controls the trainees will find on the beds at the Blake-7 Medical ICU of the Massachusetts General Hospital.

Then, the trainee enters the room and begins the initial stages of the procedure, including bed positioning (Fig 1), identification of landmarks, and the use of the Ultrasound probe to locate the vessel. Other general aspects which are occasionally ignored are encouraged and monitored, such as proper use of disinfectant gel, good communication with the patient (if conscious) and redundant identification of the patient as well as confirmation of the benefits and risks of the procedure.

The second stage of the simulation deals with the deployment of the sterile field and proper manipulation of the equipment. In fact, many of the steps of the procedure deal with effective creation and maintenance of the sterile field, which includes proper use of sterile equipment, proper opening of the line kit, preparation of the Ultrasound probe, identification of the components in the line kit (Fig 2), and final preparation of the line kit to begin the procedure.

Fig. 2. During the simulation, the trainees get familiarized with the actual line kits used at the Hospital, including descriptions of all the components and their use. Integral components of the kits include: various needles and syringes, a long wire used as a placeholder in a blood vessel once it has been accessed by a needle, a scalpel used to cut the skin, and the vascular catheter which will allow the infusion of medicines and monitoring of intravascular pressures.

After completing all these steps, the trainee is led through the steps of the procedure, with the simulation showing a perspective of the patient with the sterile field deployed and the line kit prepared. This part of the simulation focuses on helping the trainee memorize the sequence of steps, but cannot substitute practicing the procedure using the actual components of the line kit and a mannequin.

3.2 Planning the Monitoring and Assessment

As mentioned at the beginning of the section, the training sessions for the CVC Insertion Protocol currently being performed are conducted by instructor who monitors and assesses the performance of the trainees. During the session the instructor

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completes a checklist as the trainees follow the procedure. Some of the items on the checklist deal with bad practices (e.g., not maintaining good communication with the patient –Fig 3 -, improper confirmation of identity, etc.), some are related to the procedure itself (e.g., correct sterile technique) and some to general safety practices (e.g., correct disposal of sharps or contaminated materials).

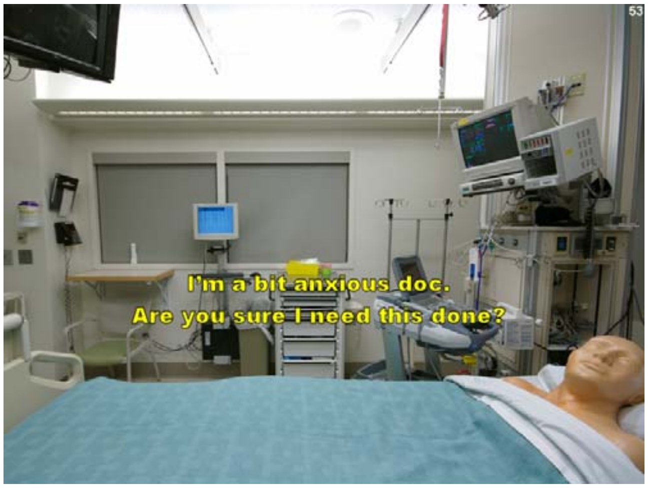

Fig. 3. Proper communication with the patient is not always mentioned in the materials explaining this procedure, an essential component that can get sidelined while the trainee is focusing on the task at hand. The simulation integrates patient communication reminders into the virtual encounter so it is less likely to be forgotten during the real encounter.

Every omission of an aspect from that checklist is a mistake made by the trainee. Therefore, each mistake results in a reduction of the score of the procedure. A simulation completed in a timely manner and without any mistakes represents a score of 100%. Each omission results in a deduction, with some omissions being considered more grave than others. Using excessive time to complete the simulation also results in a deduction. Table 1 summarizes some of the aspects included in the final calculated score.

The final score is thus an estimation of how familiar the trainee is with the protocol, and can be used as an indicator of whether the trainee is ready to move on to training sessions with mannequins or even live patients. The score is accompanied by a full report with feedback explaining all the deductions. The trainees can consult the report in order to see on which steps they failed.

Additionally, we wanted the simulation to behave as a game in some aspects, for instance, modifying its behavior between runs, in order to cover some of the special circumstances that can be found during these procedures and to make the simulation more challenging for the students. On its current iteration, the variations introduced are mostly related to modifying the default behavior of the patient, who will be unconscious in some runs and non-cooperative in some other runs. The non-cooperative version of the patient is only activated in cases where the trainee has completed the simulation successfully at least once (that is, achieved a score over 80%).

3.3 Implementing the Storyboard

The <e-Adventure> platform introduces an implementation strategy centred in the storyboard. Indeed, this storyboard must be marked up using an easy-to-use XML-based descriptive markup language. It avoids the use of more general-purpose and technical programming languages, and it lets instructors directly use the platform in implementing the videogames. In addition, and as said before, <e-Adventure> includes a simple editor that also isolates authors from the intricacies of the XML encoding, which is very useful in order to encode the more delicate aspects regarding conversations with characters, as well as conditions associated with the different actions.

Table 1. A partial list of score deductions for different concepts. Grades below 80% indicate that the trainee still makes excessive mistakes.

Checklist	Deduction
Calstat used prior to entering room	-10%
Bed adjusted to proper height, patient brought to head of bed	-2%
Patient in Trendelenberg when examining vessels with ultrasound and then returned to supine position	-5%
Landmarks appropriately identified	-5%
Time out with nursing noted	-5%
Chlorhexidine properly applied w/ sterile gloves	-10%
Gown, gloves, and goggles/face-shield used; gowned w/ hands inside sleeves	-10%
Sterile sheet from line kit used to cover field; opening matted down on patient	-5%
Tray and items set up completely prior to use including loading of suture	-5%
Line flushed and clamps placed prior to removing syringe when flushing	-5%
Patient told to expect needle stick prior to injecting lidocaine	-5%
Lidocaine used at insertion site with ultrasound in real time	-5%
Appropriate technique to reduce risk of air embolism (finger over needle hub)	-10%
Pressure tubing (if available) used to assess that needle is in vein	-5%
Guidewire always kept in hand and under control	-10%
Sharps returned to needle holder and scalpel retracted after use	-5%
After insertion, flushed air, flushed w/ saline, & clamped to keep closed system	-5%
CVC left 3 cm out and sutured in with soft clamp and box clamp	-5%
More than 30 minutes to complete the simulation	-5%
More than 45 minutes to complete the simulation	-10%
More than 60 minutes to complete the simulation	-20%

As indicated in Table 2, in the development of this simulation there was an initial effort regarding the adaptation and evolution of the <e-Adventure> platform to the new domain. This evolution was required to pass from a second-person perspective to a first-person one, more suitable for game-like clinical simulations. As it can be noted, the overall effort was reasonably low, partially due to the modular nature of the <e-Adventure> engine, as well as the modular nature of the processor for the <e-Adventure> XML-based language described technically in [25].

Regarding the creation of the initial script, it should be noted that the time reported in Table 2 includes both the conception of the storyboard and its XML encoding as required by <e-Adventure>. Since the script was created using the <e-Adventure> editor, almost all the time was spent on conceiving the storyboard instead of using XML to make its structure explicit. This significantly reduced the amount of time required, from previous experiences that required editing XML files by hand.

3.4 Implementing the Monitoring and Assessment Plan

The monitoring and assessment plan was implemented using the <e-Adventure> editor by creating assessment and grading profiles that identify which information should be tracked and reported to the learners' profiles. As with the XML script, almost all the time reported was invested in the appropriate design of the plan rather than on its implementation. Therefore, the encoding time was also drastically reduced.

3.5 Gathering and integrating the art assets

The graphics for the simulation were obtained in three photography-shooting sessions. In the first session, we visited the Medical Intensive Care Unit at the Massachusetts General Hospital and photographed one of the rooms where this procedure is usually performed. The second session included taking close-up photographs of all the materials used in the procedure (Fig 4). The third and final session simply provided additional assets for those materials that were identified as needed during the testing and improvement stage.

It should also be noted that this time estimation also includes planning for and recording voice-overs for the game and gathering sound effects for the background. Additionally, the estimation also includes the time required to consolidate the assets using the <e-Adventure> editor.

3.6 Deployment as part of the training program

If the planned evaluation of the <e-Adventure> Central Venous Catheterization game pilot is successful, it will be made generally available to internal medicine residents in 2007/2008. Deployment will entail integration at two levels: (1) on the clinical wards where the residents are working/learning, and (2) in the offices where learning objectives, which are part of the department's educational mission, are defined and tracked. The online nature of the game-like simulation gives busy residents access to the CVC training at any of the hundreds of clinical workstations available in the hospital and allows its integration into the existing e-learning infrastructure (*The Hub*) where individual trainee's progress is tracked and evaluated. This can be exemplified in the following scenario:

Dr. X is scheduled to start his first rotation on the intensive care unit (ICU) on Monday. On Friday, relevant learning materials show up in his portal page in *The Hub*, because the administration has made the CVC game-like simulation part of the ICU curriculum. Dr. X knows it is also a requirement to take part in the face-to-face CVC skills training so he takes it until he exceeds 80% in the game. His progress is reported to *The Hub*, is added to his e-Portfolio, and results in him being scheduled for a CVC skills training session on a mannequin with a clinical educator (Dr. C) on Wednesday. He does well. On Friday a patient comes in that requires a CVC and 30 minutes before the procedure is planned Dr. C calls Dr. X to get ready to test what he has learned. Dr. X quickly reviews the steps required in the CVC game using the computer downstairs. After a successful unproblematic placement of the CVC, Dr. C fills out the evaluation form on *The Hub* for Dr. X. Later that night, Dr. X adds the successful procedure to his procedure log. Afterwards the administration can show that they have fulfilled their mission (and ethical obligation).

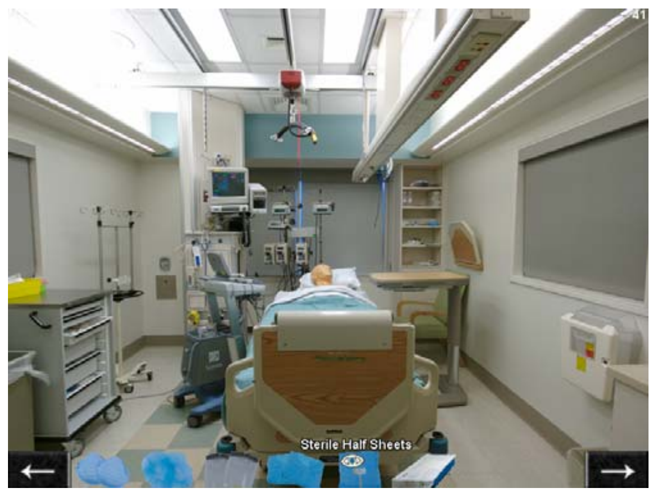

Fig. 4. All of the scenarios and objects displayed during the simulation are photographs of the actual rooms and equipment used in the Blake-7 Medical ICU at the Massachusetts General Hospital.

4. DISCUSSION

The development methodology supported by the <e-Adventure> platform suggested in this work could be potentially used to develop low-cost instructional content that improves training outcomes. The prototype developed from the case study shows some promising results as discussed in this section.

4.1 Development costs

[21] presents the results of a survey made during a session on *serious games* at the 2005 edition of the *Game Developers Conference* (http://www.gdconf.com/). The survey included questions about the costs of the developments that were being developed at the time, and most answers (26,23%) fit into the 100.000-500.000 range (with also a significant 14,75% in the 1,000,000$-10,000,000$ range). Similarly, the results introduced

in [1] estimate costs for the development of “next-generation simulations” on the 15-30 person-years range.

These figures are far beyond the typical budgets available for learning specific procedures at individual institutions. Even if it was possible to generalize such simulations to take advantage of economies of scale it would be difficult to recoup such enormous development costs. In these scenarios, the investment needs to be several orders of magnitude lower, even if it means sacrificing part of the benefits.

The total effort for the development of this case study, as described in Table 2, took about 410 hours or roughly 2.5 person-months, a figure much more aligned with realistic budgets for a learning module focused on a single procedure at a specific institution.

Table 2. Approximate number of man-hours required for each of the stages of the project and the profiles of the personnel involved (I = Instructors, SD = Software Developers, A = Artists, T = Trainees).

Concept	Cost	Profiles
Modification of the <e-Adventure> engine	50 hours	SD
Conception of the storyboard / Creation of the initial XML script	80 hours	I
Monitoring and Assessment Planning / Creation of assessment and grading profiles	50 hours	SD, I
Creation of the art assets	150 hours	A, I, SD
Deployment, testing and improvement	80 hours	I, SD, T
Total:	**410 hours**	

One of the causes of this excessive cost is that developing even the simplest 3D simulation environment has a high cost. The simulation described in this work takes a simpler approach, substituting pure 3D environments with virtual spaces consisting of navigable series of photographs. This simplification reduces the development costs, although it sacrifices realism, interactivity and depth, taking a leap back from the current state of commercial videogames.

However, in the case study presented in this work, the training sessions performed with either mannequins or live patients with the close guidance of an experienced instructor acts as a measure of realism and learning effectiveness.

When judged against that metric, neither the approach proposed in this work nor a fully interactive 3D simulation would provide a result that would allow making those training sessions obsolete in terms of mastering central venous catheterizations. But, as it has already been stated, the residents are not actually overwhelmed with the delicacy of the procedure itself, but with the requirements of the strict protocol devised to reduce the risk of infections. In these terms, the performance of this simplified game when it comes to memorizing the 98-step protocol is similar to the potential results of a more complex 3D simulation.

On the other hand, there are cases when the interactivity requirements are higher than what this simplified approach can provide (and, hopefully, the budgets can afford these requirements). In these cases, it is usually difficult to appreciate the potential usefulness of a simulation project before it is completed. When dealing with complex and costly projects, an often-feared scenario is the possibility of the resulting product failing to deliver the expected educational results.

In these cases, the approach presented here is still worthy as a prototyping methodology. The lower costs of this approach can deliver with a low risk a functioning product to demonstrate how the completed simulation would work. Indeed, these simplified games would act as interactive storyboards of the completed product.

4.2 Educational value

As several academic authors defend, the use of videogames and simulations can improve the learning process [8, 11, 14, 22, 27]. This is partially a result of a closed game cycle, where the actions result in immediate feedback [26]. But this feedback does not only provide the grounding for the acquisition of knowledge. In fact, this very cycle also engages the player in wanting to interact more with the environment. Games are motivational and engaging, and motivated or engaged students learn better and retain more information [7, 17-19].

When the approach is examined in terms of fun, there is a potential critique to this specific approach. The resulting products are not nearly as interactive and fast-paced as modern commercial videogames. In fact, moving back a few years, this game behaves much more similarly to the originally best-selling series Myst™.

However, these games have lost their impact in the commercial videogame scene, suggesting that current players prefer more intense action. Can this be an issue in terms of motivation and thus educational value? To prevent trainees from disengaging, we introduce additional elements like the fact that the play sessions are timed and the results can be publicly reported to all the participant trainees and instructors, thus leveraging the attraction of competitive games.

When examined from a purely educational perspective, the <e-Adventure> platform offers some pedagogical advantages over traditional content.

The built-in assessment mechanism provided by <e-Adventure> can be employed to automatically compute the score of the player, a task that in other game-based approaches is usually performed by an instructor during the play sessions. The trainees can perform the procedure as many times as they want and get an instant report on how well they followed the protocol and whether they are ready for a practice session with an actual instructor that will not result in a waste of time.

Besides, the adaptive behavior of the games allows the creation of game-like simulations that do not exhibit the same behavior every time they are run. In the case study, we included modifications of the behavior of the patient in order to reflect the validity of the approach to procedures that need different approaches depending on a number of non-controllable initial conditions and to make the game more challenging for the student.

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4.3 Integration with the existing E-learning infrastructure

Given that the <e-Adventure> platform can be integrated with *The Hub*, we can use it to deploy and serve the games as any other kind of instructional content delivered through the platform. When the games are launched they establish a communication with the server, allowing scenarios as the one described in section 3.6 to occur. The adaptation can thus be configured from the server using the information available through the server's implementation of the IMS LD specification described in [9].

When the execution is completed, the calculated score can be sent back to the IMS LD engine, which, in turn, stores that information for further executions of the game and can publish the score along with the completion time to the student's profile. This publication of the score, apart from leveraging the competitive nature of students, serves a clear educational purpose. The instructors can check the grades of all the residents and decide which of them are ready to start participating in the instructor-guided practical sessions.

It should also be noted that the use of existing e-learning standards such as the IMS LD specification does not limit this kind of integration with the e-learning infrastructure used at Massachusetts General Hospital (.LRN), but allows it to be deployed wherever standards compliant e-learning tools are used.

5. FINAL REMARKS

Although there is broad agreement in the need of improving medical training that precedes the interaction with live patients in order to maximize safety, the realities of daily life at a major hospital constrain the opportunities for training experiences. The current use of low-technology mannequins is a good approach for training before proceeding to live patients, but finding time for these guided training sessions is almost impossible.

The use of advanced forms of simulation would deliver an improved experience, but their costs are far beyond the training budgets of specific units such as the MGH Medical ICU. The use of educational adventure games, however, can reduce the time (and hence cost) associated with guided sessions and offers the trainees a way to focus on learning complex procedures that consist of a number of steps and branching decisions beforehand so that the steps do not subtract face-to-face time needed for practicing the necessary motor skills.

The genre of adventure games has proved efficient for acquiring this type of knowledge [15]. Even without featuring amazing graphics and sophisticated interaction, they can provide an engaging experience. The experiences with portable consoles like the Nintendo DS suggest the existence of a market for engaging titles without last generation graphics or interactions (like the specifically educational *Brain Training* or the simple but engaging gameplay of *Phoenix Wright: Ace Attorney*, both on the Nintendo DS console). Therefore, there is room for lower budget educational adventure games, provided that the contents engage the players.

If we are willing to accept the reduction of interactivity and eye-candy and use specific educational game engines, there is a potential rapid development process that incurs higher costs than traditional teaching materials for clinical procedures, but is still within the boundaries of training budgets.

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