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GAME-BASED TRENCH SAFETY EDUCATION: DEVELOPMENT AND LESSONS LEARNED

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SUMMARY: *In collaboration with a college teaching construction trades, the authors engaged in developing and deploying a serious game focussed on teaching trench health and safety lessons as an initial investigation into applying edutainment in the construction trades. This paper reviews the background of using interactive technology in construction trades training and presents the observations taken from the developers, teachers and students involved and subsequent conclusions drawn based on these observations. The broad lessons learnt indicate that serious games offer an engaging and innovative medium for delivering training to students who are more comfortable with hands-on learning for a hands-on trade. Although studies are still underway in assessing the long term benefits in retention, the students and teachers involved found the use of gaming technology to be an overall positive experience with some immediately demonstrable benefits. Furthermore, the potential for adopting serious games in educational programs will only grow as interactive computer technology only becomes more and more ubiquitous in society. This said, challenges remain in measuring the long term impact, and costs associated with developing and delivering the interactive content to the students and subsequently finding ways to reduce those costs and maximise the positive benefits attained using such technology.*

KEYWORDS: *serious games, edutainment, health and safety training, trench safety, knowledge transfer, visualization.*

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1. INTRODUCTION

Changes in population demographics are having a significant impact on the standard level of worker expertise, especially in the North American construction sector. Lack of experience is found to be a major root cause of making construction errors (Riemer 1976; Riemer 1979; Lim and Mohamed 2000), and perhaps most importantly of sustaining injury due to unsafe work practices. As a consequence of the baby boom, many experienced employees are exiting from the workforce in a fashion that could be characterised as a “shockwave”. General and specialized construction knowledge must quickly and effectively be transferred to their replacements. Complicating matters is the fact that the rapid advancements of disruptive innovations such as sustainable construction technologies, systems and materials are being introduced to the industry and new practitioners are required to install and maintain a broader variety of complex systems, changing the current construction ontology.

Presently, we see a shortage in nearly all classifications of skilled trades (NSCIC 2002) which is expected to rise in the near future. The lack of experienced workers to mentor new practitioners increases the potential for making mistakes. These errors can lead to quality, performance and health and safety issues. Specifically, statistics show that young workers are at a much higher risk of injury than workers of any other age group. Half of workplace accidents involving young and novice workers occur during the first six months on the job (statistics available at HRSDC, AWCBC, NWISP, OSHA [1]), and one fifth in the first month. Thus, developing alternative approaches for communicating construction knowledge and provides training, including health and safety training, is becoming particularly important.

Employers must ensure the safety and health of their workers and ensure that their actions or lack of actions do not cause anyone else harm. By law they are required to share information necessary to communicate and control hazards, ensure workers are competent to perform the tasks assigned by instruction and training and ensure that tools and equipment are used properly. Training must be adaptable to ever evolving conditions and needs encountered. A construction work site is an entity in constant evolution and each phase requires its own specialized training to teach new personnel about dangers, hazards, regulations, and such. The following section describes some more common training methodologies and approaches used to communicate construction knowledge and related health and safety material.

1.1 Teaching Trade Students

Traditional learning practices in the construction sector are based on “hands on” experience as typified by apprenticeship programs. Initially, the student, with the supervision of an instructor or mentor, assimilates the information by reinforcing the knowledge through continuous practice of the individual tasks. This learning mechanism is related to behaviourism theory and provides feedback to the student in the form of positive and negative reinforcement. Behaviourism is one of the pillars in teaching practical skills, and by consequences, trades; it is by repeating the action of laying one brick after another that a student mason will acquire a sure hand and be able to raise a wall faster and better after each attempt. It is by repeating the task over and over, with the proper feedback from the instructors, that the students’ work will show the desired results - quality workmanship, greater productivity and fostering a safer environment to work.

Once the student acquires enough experience and independence, project-based learning and problem-based learning must be used to instruct and to coach the student to overcome challenging and open-ended problems with multiple solutions. A project-based learning scenario requires that the student has specific content knowledge or skills to produce an end-product. A typical example is the excavation of a trench, which involves the understanding and the implementation of a multi-step process. A problem-based learning scenario provides the student with a problem he/she must solve by exercising their own judgment to find a good solution to the problem. These learning mechanisms are related to the constructivist model of human cognition and rely on dynamic interactions with the environment (Øhra 1998; Panko et al. 2005).

[1] HRSDC, Human Resources and Skill Development Canada
OSHA, Occupational Safety & Health Administration USA
AWCBC, Association of Workers’ Compensation Boards of Canada
NWISP, the National Work Injury Statistics Program of Canada

The theoretical and fundamental knowledge is acquired from the beginning in a classroom. Its underlying principles are defined by the constructivist learning theories which emphasize the role of experience in learning via schoolroom environments. The classroom material allows a student to acquire the fundamentals or reinforce existing knowledge for current practitioners, and provide a means for accessing, but not necessarily gaining, new and evolving information. To characterize and analyze the knowledge transfer framework, it is important to differentiate between training, which can be characterized by the way knowledge is delivered as an experience, a learning which is characterized by the effectiveness of the delivery. Training is essential to acquire knowledge in which the information is constrained, by space i.e. city bylaws, by time i.e. construction process or by societal influence, i.e. working as part of a team. Often, circumstance creates the training content to fill a void outside the regular curriculum. For example, in Canada, the most consistent formalised methods of knowledge transfer in the construction sector are the provincial building codes. These are a set of legal requirements that guide the minimum standards that any new building must meet. While the building code specifies performance, even to the point of describing what a finished structure must be like, it does not specify how to construct a building to meet that performance, nor does it specify the details that are required. For this reason, organizations provide best practice guides that are a step-by-step set of instructions to carry out the task. The worker is then trained on how to follow the step-by-step instructions and to understand the overall process.

College construction programs further formalise this approach by providing a rigorous curriculum covering the material to be learned systematically and including supporting theory and regulations where applicable. In contrast, when serving an apprenticeship a new worker may only have the opportunity to learn about practices associated with the jobs being worked on and opportunities on the job site to explain why things are done and relate the situation to other construction knowledge such as the building codes or safety regulations are limited. Unfortunately, college programs cannot afford to go as deep into subject material as a real-world job would do due to both time and resources constraints. Combining an apprenticeship with college education, especially for regulated trades, can provide the best of both worlds but is still limited by availability of teachers, journeymen and ways to present potentially dangerous topics.

1.2 E-Learning and Serious Gaming

Learning and knowledge transfer in the construction sector stand to gain significantly by embracing the digital tools to address some of these shortcomings. Other forms of knowledge transfer have already been used. Video-based guides are becoming popular, and while they have a high degree of realism, once they are delivered, they cannot be modified, and they do not always show a practitioner sufficient detail for a given step or process, Furthermore, videos are difficult to consult on site, and can be awkward to search through to review a particular operation or task. Perhaps, most importantly, these tools tend to be passive and do not necessarily allow a practitioner to test their understanding, so they must wait until they physically try to perform an installation before they know if they understand the material. Nevertheless, they demonstrate that there is potential for gain by applying technology to the training of trades people.

With disruptive technologies such as the Internet, virtual social networking, smart-phones, and game consoles already adopted in an organic fashion by the under 30 generation and often reluctant but growing acceptance by the older generations, learning is entering a new phase. The subject and the related content to be taught are not always being accepted by the younger generation who are immersed in entertaining visual, social and communication technologies although experiments with technology enabled versions of traditional face to face teacher-student and student-student interactions using virtual classrooms and learning portals have met with some success (Beheshti et al. 2009). Conversely, the baby boomer generation working in the construction sector may find video games unrealistic and a frivolous way of learning. A middle ground is possible: in one paper, Zyda (Zyda 2005) describes a Serious Game as "*a mental contest, played with a computer in accordance with specific rules that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives*". Traditional VR training systems can be efficient at providing problem-based learning and project-based learning scenarios focusing on on-the-job training. These simulations allow the students/trainees to comprehend the consequences of their actions, improve their confidence and prevent exposure to unnecessary danger until task familiarity is acquired (Ponder et al, 2003).

Research shows that advanced visualization and Virtual Reality (VR) environments can assist and enhance the users' learning experience (Haymaker and Fischer 2001; Lipman and Reed 2000; Messner et al. 2002; Op den

Bosch and Hastak 1995; Schnabel and Kvan 2002; Bowman and Wingrave 2001). With the help of interactive training systems the users can visualize and have appropriate interactions with the computer-generated models, thus minimizing physical training requirements and avoiding costly and hazardous mistakes. Recent studies have shown that if advance technologies such as visualization and VR are integrated appropriately within built environment academic curriculums, they will provide a good foundation for the new workforce (Horne and Hamza 2006). However, a recent report (Dawood 2009) on the VR Roadmap "A vision for 2030 in the built environment" suggests the training of workers is a big challenge and needs significant R&D. The report also emphasizes the fact that hardware and software technologies used should be intuitive in order to cater to the new generation workforce.

Highly immersive training environments already exist to train novice workers on specialized jobs and are very efficient for skills training, allowing the students to learn "*by doing*" and "*by feeling*" through multiple tactile feedback from the simulation environment. The technology is very efficient for situation training, allowing the students to learn "*by seeing*", "*by experimenting*" and "*by socializing*" through feedback from other team members at the scene, supported by a greater degree of coordination between team members. Several challenges remain when implementing advance simulation and visualization technologies into the construction industry depending on the focus of the training. The classical one is the cost, i.e. the traditional VR environment requires significant financing with the consequence that the potential return on investment may only be appropriate for highly skilled and potentially dangerous tasks like operating heavy equipment. The cost can be offset by commercial video game platforms which are mature enough to take the lead in more common skills and situation training. The second problem is how to move the simulation and visualization technology from secure office space to where the technology is needed, i.e. the work site. The third would be to develop applications with construction industry specificities in mind, i.e. education background, generation differences, multiple ethnicities and languages (Von Baeyer and Sommer 2000; Beheshti et al. 2009).

To support studying these issues, a visual-based interactive computer tool has been built to aid in health and safety training. This tool was then used to present trench safety content as part of the educational material for several classes of construction trades students at a community college. Health and safety issues are of particular interest, as material usually must be presented in the classroom through paper-based course material or videos since field training and or lab work cannot ethically create unsafe conditions to illustrate the dangers and consequences, nor cover all possible facets of the material.

2. DESIGN PRINCIPLES

Colleges in Ontario teaching the ticketed construction trades have the bulk of the content of the curriculum specified by the organisations that govern the trades, but freedom remains with the teacher to decide how to present the material. Some materials like health and safety are often taught throughout the program but without opportunity to reinforce the lessons through practical application of the knowledge. Our effort addressed the specific topic of trench safety which includes hazards like falling in, being struck by falling objects, trench collapses and trench collapse causes and prevention. This material is currently presented using a handbook provided by the CSAO, which can be found online (CSAO 2007) and includes a standard quiz at the end for assessment of mastery of the material. Supplementary lesson material includes classroom discussion, videos and accident statistics.

Unfortunately, the students will rarely have the opportunity for practical application of the safety lessons until much later when they are at a job site, and the comprehensiveness of the knowledge application is limited as it is not industry practice to build lots of different safe and unsafe trenches just to bring a lesson home. This is where it was hypothesised that a serious game could make a significant contribution to the course by engaging students and reinforcing the lessons covering issues which cannot be shown safely in the field or in a timely fashion. In particular this echoes the broad belief that that effective training is important both for learning and to prevent accidents and disasters due to faulty workmanship (Barsoum et al. 1996) and that such training should be as analogous as possible to the material being taught.

Several design goals were selected up front as the basis of our efforts. A game was selected as the delivery platform as it was believed it was the most engaging and interactive mechanism that we could adopt that would provide the opportunity for the students to reinforce their lessons and provide a quantitative mechanism to assess their mastery of the material. It was also thought by the team and the collaborating college teacher that most students would also have significant familiarity with playing computer game thus easing the acceptance of the technology by the class. A game also gives the students the opportunity to work independently and proceed at their own pace and try and fail with no concern for consequences. Furthermore, if the game is carefully crafted it can provide non-judgemental support when students do fail and reward successful efforts.

Review of the booklet on trench safety (CSAO 2007) and especially the included review quiz revealed that the material was already grouped together by major topics: background, causes of cave-ins, protection against cave-ins and other hazards and safeguards. This naturally led us towards a scenario based game structure where each scenario would cover a different part of the material. The first scenario was conceived to be introductory to acclimatise users with interacting with the game environment while teaching just a few basic safety points. The scenario storyline focussed on getting a toolbox out of a trench safely. The premise of the second scenario was to analyse what caused a trench cave-in that occurred overnight in order to be ready with information when the inspector arrives. A number of red hearing possible causes were included in the scenario. The goal of the last scenario was to make the correct decisions about how a number of trenches should be dug and shored to minimise cost while meeting safety requirements for varying soil conditions, trench depths and space availability on the site.

Significant effort was made to provide a realistic looking environment and rich interactive content to maximise the student`s intuitive correlation between the lesson being taught and situations where the knowledge would be applied in the field (see Fig. 1). Adoption of this design goal was based on feedback the team had received during a previous investigatory project developing a computerised framework for presenting best practices guide for topics including how to install windows into exterior walls (Dickinson et al. 2009; Woodard et al. 2009) (see Fig. 2). In this project a game was created that asked the user to select the correct action to take at each step in the sequence by selecting between various icons depicting different materials or tools indicative of the action. It was hoped that this would force the users to actively think about each step and thus internalise the process being taught. The feedback had made specific note that better results would be achieved by creating the most lifelike experience possible by getting the details right, for both sight and sound, by minimising the use of text, and by making sure the interface is natural to the application and does not interfere with the experience.

FIG. 1: Scenes from the Trenching Safety Game

FIG. 2: Screenshot from the window installation guide.

It remains that subjective factors will decide the adoption and the full participation of the student, and the approach is to encourage student engagement by creating the scenario so it will do what a human teacher/mentor would do, and to do it in a way that matches each individual learner. One popular mechanism to do this is by introducing avatars into the game. An avatar represents one party, a pedagogical agent, in an interactive exchange with the objective of increasing the motivation of the players. Avatars come in three common forms as described below:

1. A typical avatar in e-learning and edutainment occurs with an emulation of a teacher or an instructor to coach and to guide the student through the teaching material and then to correct and to give explanations on any mistake made. The avatar is always present in the background and can intervene and help the student overcome an obstacle by giving clues based on the level of proficiency of the student. In our implementation, the supervisor (aka foreman) is represented by an avatar who gives the instructions to the student by describing the problem that needs to be solved or steps to be taken.
2. Another common kind of avatar operates as an autonomous agent of the application and simulates human activity. These avatars can be represented using simulated humans or vehicles, known as "bots". Examples of this might be a co-worker doing some work or a truck unloading its cargo. Bots can also be represented purely by using sounds, such as the sounds of hammering in the background and are present to enhance the level of realism of the scene.
3. The most sophisticated avatar is one the student can control in the game and interact with other characters in the scene to perform teamwork activities such as in a virtual social network or multi-player scenarios. This aspect was not implemented in this prototype.

The use of avatars comes from assumptions in eLearning theory that using character simulation should engage and motivate the learner according to the following principles::

- Simulated characters motivate learners by being credible, trusting, helpful, and are always present for the student.
- Simulated characters induce interest and fun.
- Simulated characters enhance soft skills learning.
- Simulated characters improve how the message is delivered.
- Simulated characters can drive higher learning by allowing higher rates of completion, learning and retention.
- Simulated characters can be tuned to any age bracket
- The instructor has, potentially, more control over the learning environment and interactions than in a classroom setting due to the one-on-one communication between the simulated characters and the students.
- Systems based on simulated characters provide the potential to capture a large amount of rich data, both quantitative and qualitative by logging the interaction as it occurs.

Other design principles were that to maximise usefulness, any learning tool could not disrupt existing teaching plans. To integrate the game with the current curriculum the decision was made to embody many of the answers to the questions in the review quiz in the game, so the students would still answer the quiz, as part of their grading process, but while using the game as a supplementary resource. Other classes would continue to have the material presented in the traditional fashion to act as controls in later follow-up studies to test the long term retention of the material through subsequent re-testing. The decision to use the tool was left to individual teachers as to how it fit their teaching approach. While this likely leads to a certain amount of confirmation bias, it is also typical of how new teaching techniques are traditionally introduced.

The selection of the delivery platform was driven by the principle of making a tool that would be easily available to all. The nearly ubiquitous personal computer was a logical choice as the colleges already have extensive computer labs available for use by the teachers and by hosting the game on a networked computer it was possible to give students access to supplementary resources that compose a regular part of the teaching materials for the studies. As mentioned above, the extensive use of realistic graphics to communicate the situation and provide context to the experience provides a good mechanism to avoid many challenges associated with potential language barriers. In fact, for health and safety, a primary mechanism for identifying hazards involves looking around and being aware of your environment. Teaching them to look around and pay attention to common audio warnings (e.g. truck beepers) in a visual game is far better analogy to real life situations compared to multiple choice questionnaires or classroom analysis of case studies.

Personal computers are not the only way such interactive and rich content can be delivered these days. Constant improvements in notebooks' and other portable hardware and growing broadband connectivity mean that the similar games can technically be delivered on smart phones or over the internet or company LANs in browsers.

3. IMPLEMENTATION

The game itself was developed using Microsoft XNA Game Studio 3.1 (Microsoft 2009b) in the Microsoft Visual C# 2008 integrated development environment (Microsoft 2009a). This framework provides the basic functionality for creating and executing simple games including a standard way of defining, pre-processing and rendering geometry, audio and video to be used during any game and the basic game loop which captures user input, computes game responses and renders results. XNA can be used to develop games for Windows, Xbox and Zune hardware platforms. Other game platforms exist with more prebuilt structure to the games but this platform was selected due to its easy availability and confidence in the ability to develop a tool that would allow the researchers to understand the implications of various technological trade-offs.

The game was designed to be flexible and reusable. A traditional model-view-controller (MVC) was chosen as the fundamental architecture of the system. In an MVC implementation, the three components of the system are responsible for specific data and interactive features. In the system used here, the view component was responsible for graphical elements, such as the display of 3D geometry and 2D graphical overlays, such as heads up displays, and text. The controller component was responsible for user interaction, such as navigation or object interaction. The controller also maintains the timing of the system, and adjusts and sets time steps as necessary. The model component contained the logical relations between objects, and determining what the system response would be to user inputs. The three components communicated directly through function calls for routine communications or commands (i.e. those that occur each time step) and through messaging for infrequent communications. The architecture is shown visually in Fig. 3

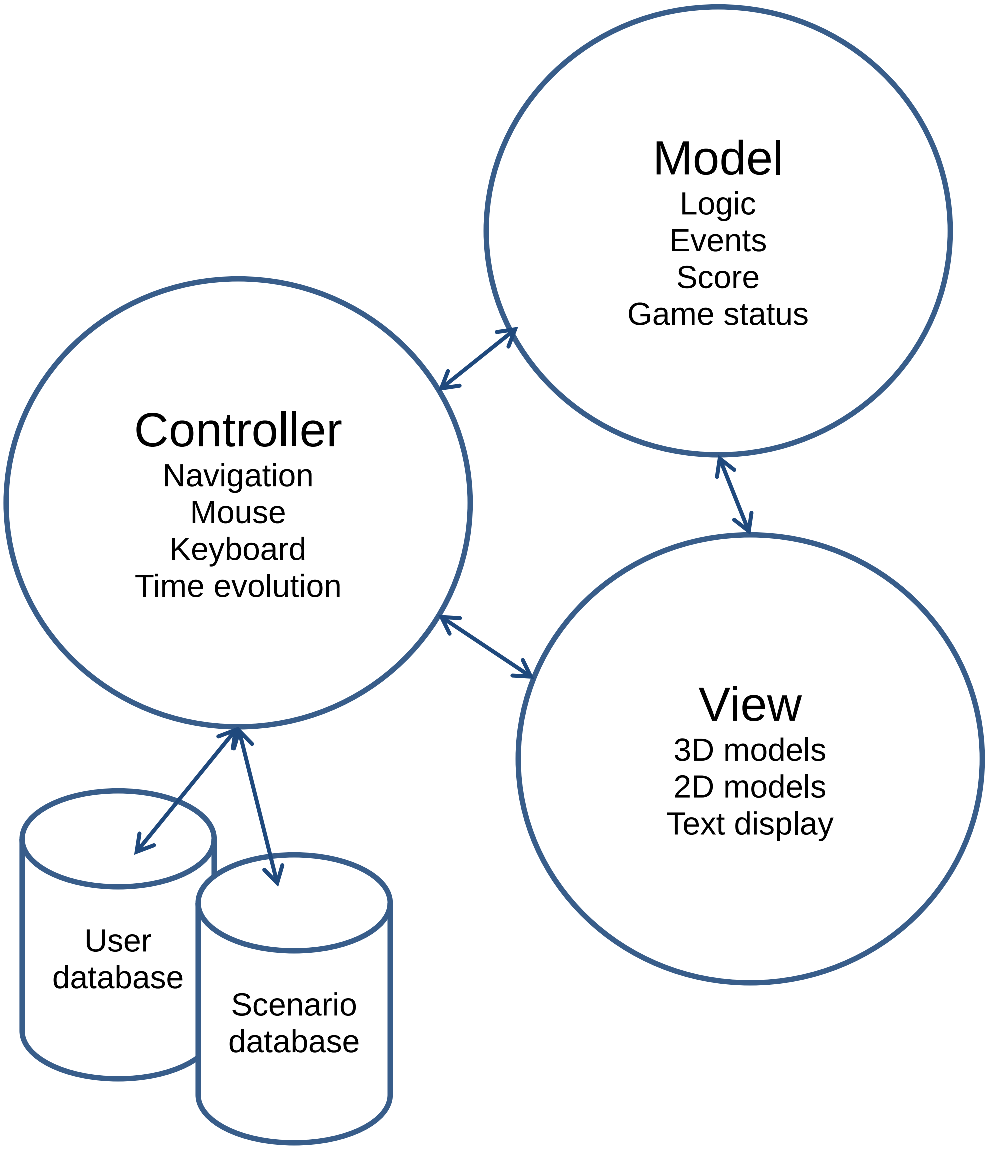

FIG. 3: Model View Controller architecture used in trenching training game.

The game was designed with the idea of presenting multiple reconfigurable scenarios covering the material to be presented and assessed in logical chunks. Students are first required to log in to the game so their progress, including time taken, scenarios completed, scores achieved, etc. can be recorded for use by the teachers. Log in names and PIN numbers were randomly generated and distributed by the teacher to ensure anonymity of the students for the research purposes. Once logged in students are presented with a scenario selection screen outlining the basic goal of each scenario to be completed. Students select a scenario to play and further introduction to the game is displayed while geometry is loaded. Students begin playing the game scenario immediately after this screen and upon completion will receive feedback on their performance. See Fig. 4 for illustrations of these screens.

FIG. 4: From left to right, top to bottom, the login screen, the scenario selection screen, the splash page for a loading scenario and the concluding screen for a game scenario.

While playing, students interact with the game by moving freely through the 3D environment as if they are walking (though they are prevented from walking through most geometry). The mouse is used to control their view point and interact with objects in the environment by clicking on them. The visible cursor will change to provide clues about what ways the user can interact with the object in the environment. People exist in the scenes and can often be interacted with through pop-up dialog boxes. Interacting with other objects can cause 2D drawings or posters to be displayed to make it easier to convey detailed information commonly found on paper on construction sites.

The game is reconfigured using multiple XML configuration files. For each game scenario there is a logic.xml and graphics.xml file. For the entire game there is a single scenarios.xml file which specifies where each scenarios respective logic and graphics configuration files are located. Implementation of this functionality was broken into four main code groupings:

- Logic – the intelligence of the game specifically defined through a logic.xml file containing objects, conditions and events. The relationship between logically entities and graphically rendered entities is preserved by using the same identifier for the element in both the logic and graphics xml files.
- Graphics – specifies all visually rendered objects including embedded videos, 2D elements and 3D models that are used in this scenario. Each objects initial properties like position, orientation, collision, motion paths and visibility are defined in the graphics.xml file as well as a unique identifier shared by both logic and graphics drawing routines. Mentor avatar appearances are defined in this file and basic robot avatars behaviours (e.g. the moving truck) are also defined here (see the previous section).

- Tools – a collection of reusable methods and classes such as routines for parsing xml files, reading the provided collection of scenario descriptors or writing out the log file recording the student's progress in the game.
- Game – the high level game control including the game loop of input, update and output, and high level game state control including login state, menu display state or scenario selection state.

The configurable logic of each scenario defines the lessons flow and the rules it represents embody how the game environment responds to the user and thus what lessons are delivered. The logic base is simple but elaborate behaviours can be achieved by building networks of relationships between logic elements. More specifically; Objects representing tangible assets that can be interacted with, Conditions represent numerical quantities like scores, amounts of materials or counters associated with other elements. Events are a combination of a set of tests of conditions and actions to be performed if all conditions are met. Users can interact with these events through combinations of objects, menus, proximity sensors and timers.

For the current trenching training, the material was built into three sections, each taking place on a common simplified construction site. Each scenario was built with an internal narrative and an objective for the student that was separate from the learning objective. It was felt by educators that having a storyline would increase engagement by the students. The learning goals of the three scenarios can be broadly described as general trench safety, causes of trench collapse, and protection from collapse, respectively.

In the first scenario, the student enters the game with the instructions that it is their first day on the job, and their immediate task is to get a cup of coffee, however to accomplish that, they are told they must retrieve a toolbox from the bottom of a trench. To safely retrieve the toolbox, the students must avoid incorrect entry points (they are warned by their supervisor when they attempt to enter unsafely), and locate the tools needed to enter the trench correctly.

In the second scenario, the students are informed that there was an overnight partial trench collapse, and they must investigate some common sources of trench collapse, including improper storage of equipment, improper trenching for soil conditions, recent weather conditions, and surcharge. The students go to each potential cause in turn and must decide if it was a contributing factor.

In the third scenario, the students are told that on the day before a long weekend, the site supervisor has not come to work, and they are in charge. In this scenario, the student is responsible for the planning of five trenches on the job site, each with their own soil types, obstacles and shoring requirements. They must balance space and resource considerations with health and safety requirements to arrive at a safe solution.

In addition to increasing knowledge required, the scenarios also increased in complexity, and potential for failure. In the first scenario, the students were prevented from conducting themselves unsafely by means of a supervisor who would stop and warn them before they could act unsafely. By the third scenario, there were few such restrictions, and it was possible that a student's actions could contribute to the avatar of a "co-worker" being hospitalized.

4. LESSONS LEARNT

Developing and deploying the trenching training serious-game allowed for numerous observations and lessons to be learned, from the point of views of the developers, educators, and students, who may have had different expectations and perspectives. In this section, we provide a discussion of observations, data, and experience of the developers, educators, and students, and lessons they provide about the development, deployment and use of the current tool.

4.1 Game Development

The health and safety prototype used the official guide (CSAO 2007) as the principal foundation of knowledge. This was done since the researchers are not content experts with regards to Trenching Safety and that the material presented needed to meet good standards to be used for training workers who will be exposed to these situations in real life. One benefit of using the same official guide in the e-Learning prototype as used in conventional training is that it creates a frame of reference to analyze knowledge retention in direct comparison to current teaching practices. Another benefit matching this content with the college students is that it avoids the challenging questions that must be usually be addressed when developing new teaching materials and the potential pitfalls of mismatching material and existing expertise. We believe a computer teaching tool cannot make up for poor teaching material.

Development of the content for the tool was a very cyclic or iterative task and we have concluded that making tools to ease the content development process is very important to both improve the quality of the content and reduce the effort and time required to realise usable content. Furthermore, ultimately these tools must be extremely intuitive and simple to use if there is an expectation that serious game use can achieve broad adoption. For example, content would need to be developed by people who already know and teach the material in the construction trades and their expertise is their trade and in teaching, not in game design, geometry modelling or logic representation of user action and game response. One promising way to address this would be to create reusable content and reconfigurable and flexible games so that new content can be achieved by duplicating or swapping game elements and altering existing examples to create new scenarios.

Broad adoption will also depend heavily on the perceived cost and benefits of the approach, where development time, resources and learning-curve, reusability, ease of delivery/deployment, storage, and etcetera must be compared to traditional approaches. Having the tool automatically track progress of the students and classes and summarise the data for the teacher to act upon is another potentially significant benefit, especially for distance learning situations. Objective measures of these metrics are impossible based on one trial development and deployment of the tool and content but our expectations are that development of content at least will be significantly more resource intensive compared to traditional teaching material. We believe, but are as yet unable to prove, that in the long-term the reusability, effectiveness and ease of delivery will provide sufficient benefits, especially in areas like health and safety where hands-on lessons are impractical or unethical and where the lesson retention is very important.

4.2 Classroom Deployment

The trenching tool was deployed in three construction trade classes, earlier in 2010, at Conestoga College located in Waterloo, Ontario, Canada. The tool was used in a computer lab environment under the supervision of the class teacher as complementary extra material to be used while answering the standard quiz. Student identities have been kept anonymous from the researchers but logged so that a subsequent testing of the students in the fall can related test marks and provide some quantitative measure of any change in retention of the material over control groups made up of other construction trades classes that did not use the tool. We expect to observe a higher level of content retention by students who used the tool in comparison to the control groups but must wait for results to support that expectation.

In the beginning, certain assumptions were made how the tool would be used. It was assumed that the tool would not be stand alone, and that it would be part of a classroom lesson. Likewise, it was expected that the students would have access to, and would actually use other resources when using the tool, in this case, the CSAO trenching guide (CSAO 2007). In fact, the difficulty of the scenarios was structured to almost require the use of these tools to achieve best results. In practice, the students alternated between using the tool and the trenching guide as anticipated. When the tool asked the students for input, they would refer to other material for the "correct" answer, indicating some level of processing and applying the information from the traditional manual.

It was also expected that the students would be independent when using the tool, and there would be little collaboration between them. When students became "stuck" or unsure what to do next, or what the correct answer was, systems were built into the tool to nudge the student into the next area. In practice, the students would discuss where they were with their peers, and would use this feedback to choose their next action. This can have both positive and negative consequences, and will be important for the deployment of future tools. It was also observed that students were not all familiar with first person style computer games and those that were found interacting with the tool significantly easier and were less likely to need further external assistance.

These results of the actual use in practice can lead to contradictory conclusions. On one hand, the fact that the students were going back and forth to different material sources to complete tasks implies that they had a greater level of engagement, however the fact that they would often seek help from their peers implies a lower level of interest and engagement. Finally, students were also provided an opportunity to voluntarily give anonymous feedback. 57 of 65 students chose to provide feedback, which supports a conclusion of greater engagement.

In the feedback sheets, students were asked to provide their top two things they liked and disliked about using the tool. Table 1 gives the top likes and dislikes, and the number of responses, with similar responses grouped together.

TABLE 1: Top student feedback comments and number of people voicing each opinion.

Likes		**Dislikes**	
Quality of graphics	12	Wasn't enough guidance	13
Interaction	11	Navigation control scheme	9
Real-life scenarios	7	Felt system had bugs	7
Informative	6	Quality of graphics	6
It feels like a game	5	Interface control scheme	4
Ease of learning how to use	5		

Of interest, is that the majority of the "likes" can be characterized as being supportive of the use of alternate teaching strategies that involve interaction, feedback, and the use of real life scenarios to help their learning. Conversely, the majority of the "dislikes" can be characterized of being critical of the specific implementation of a game based approach. Improving the introduction of the interface, and providing greater context sensitive help may be a simple way to increase the value perceived by the students.

The choice of having a first person perspective was deliberate in order to provide an experience as close to that which would be had on the job. Observations indicate that some users find controlling a first person perspective (looking around) and moving to be un-intuitive with a mouse and keyboard. Upon reflection, it seems that any control system we could define using a traditional computer keyboard and mouse would have similar issues. In the future we would plan to have a more instructive tutorial scenario devoted to mastering the controls alone, with no educational content so that proficient gamers could skip the interface lesson while a better game orientation would be available for those who need it. Class time would also have to be budgeted for this tutorial scenario.

Casual observation did seem to support continued embedding of traditional content in the game, like videos, diagrams and even official written material as supportive of creating the analogy with real-life circumstances. Like-wise, making objects the students would normally interact with on the job interactive in the game furthered establishing the validity of the lesson. Instructor feedback also noted that the use of avatars, both 2D pictures of workers beside dialog boxes and 3D people that the user could interact with in the game to provide the source of feedback and instructions made the game seem more consistent.

5. FUTURE

While the early results are encouraging, there is still significant remaining work in this field. One fundamental issue is that currently, the common practice to measure effectiveness of alternate training methods is through surveys (as was done in this paper). This is sufficient to gather a measure of student interest and engagement; however this is a secondary metric. At the end of the day, any new technology should be measured by evaluating the degree of knowledge transfer and subsequent retention of and ability to apply the trained material. To that end, we are continuing work, and are engaging in a study that will measure immediate and 6 month retention rates of material presented through the use of a training guide, as well as similar material presented through conventional techniques to see if there is any difference in the level of information retention after 6 months.

Another aspect that needs to be addressed is to measure the efficiency of knowledge transfer, in terms of the time needed by a learner to acquire new knowledge, as well as the time needed from an instructor to prepare materials. Even if a technique is incredibly effective in terms of knowledge retention, it must still fit inside an overall curriculum, and cannot draw away from other material. To this end, we are anticipating studies that will measure the trade-off between the time invested by instructors and students and the overall degree of effectiveness to help identify any trends.

Once these areas are covered, we foresee additional work on easing the barriers associated with content generation and reuse. This would allow individual instructors to more easily customize content to fit their particular audience, and update information to conform to local best practices. The principle challenge for this remains the fact that the content experts in the constructions trades rarely have the special computer expertise or access to specialised software that game development currently requires. One potential solution to this would be for the construction trades associations to take a leadership role in developing some reusable and reconfigurable game content much in the same way they already publish handbooks and manuals for use by students and practitioners of their trades.

Other work is also needed to make the use of interactive visual knowledge transfer tools more ubiquitous and stand alone, so they can be used remotely, such as on ruggedized computers or smart phones. Finally, we foresee these technologies applied to not just health and safety topics, but also to general technique training, where they may be used to augment and reinforce traditional instructions and increase the productivity of the sector. In fact, a recent publication describing a VR based training tool focussing on improving the productivity of construction managers working with off-site production came to similar conclusions (Nadim et al. 2009).

6. CONCLUSION

It is clear from our interactions with teachers and students in the trade college programs that there is significant active interest in using gaming technology to present lessons in an engaging fashion. Also, we believe this approach is more effective in terms of long term retention by establishing a rich learning experience closely mimicking the construction environment and circumstances where the lessons learned would be applied. While experiments to refute or support this belief are only beginning there is already a considerable amount of anecdotal evidence and growing use of similar approaches in other areas including the military, medicine, and emergency response to name a few.

As we continue our work we will strive to quantitatively measure the impact of serious gaming and the costs of implementing it as an addition to standard professional materials available to people in the construction trades. As mentioned in the previous section, there remains a significant amount of research and development to address barriers to the broad adoption of gaming technology in the construction trades, especially in the area of easing custom content development by the teachers for use in their specific courses.

In conclusion, we believe that game technology has a definite future in the constructions trades alongside the existing teaching repertoire, especially for teaching material that is potentially dangerous or hard to present in context to its application due to constraints on material resources and time or due to safety considerations.

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