SMILE: an immersive learning game for deaf and hearing children

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ABSTRACT
This paper describes the implementation and evaluation of the second iteration of SMILE (***S****cience and* ***M****ath in an* ***I****mmersive* ***L****earning* ***E****nvironment*), an immersive learning game that employs a fantasy 3D virtual environment to engage deaf and hearing children in math and science-based educational tasks. In this second iteration we (1) combine strategies used in commercial computer games with lessons from educational research on learning and motivation in order to increase the effectiveness of the application and the fun of its use, and (2) assess usability and appeal through a user study. To our knowledge, SMILE is the first bilingual immersive VLE (Virtual Learning Environment) for deaf and hearing students combining key elements of successful computer games, emotionally appealing graphics, and realistic real-time 3D signing, with goal-oriented, standards-based learning activities that are grounded in research on effective pedagogy.

Keywords
Virtual Reality, Sign Language Education, 3D Animation, Virtual Learning Environments

1 Introduction
The objectives of the SMILE project are: (1) the development of an effective and enjoyable immersive game in which deaf and hearing children (ages 5-10) interact with fantasy 3D characters and objects and learn standards-based math and science concepts, and (2) the investigation of its educational benefits. This project is an initial step toward the higher goal of integrating research in K-12 math/science education, bilingual approach to STEM (Science, Technology, Engineering and Mathematics) education for deaf children, and interactive learning in an immersive, animated virtual environment.

SMIILE is an interactive virtual world comprised of an imaginary town populated by fantasy 3D avatars that communicate with the participant in written and spoken English, and American Sign Language (ASL). The user can explore the town, enter buildings, select and manipulate objects, construct new objects, and interact with the characters. In each building the participant learns specific math/science concepts by performing hands-on activities developed in collaboration with elementary school educators (including deaf educators), and in alignment with standard math/science curriculum. The application is designed primarily for display in stationary projection systems (i.e., the Fakespace FLEX [1]) but can also be viewed on a single screen immersive portable system [2], or through a stereoscopic head-mounted display unit. Children travel through the virtual world using a 6-dof (degrees of freedom) wand, a dance mat, or a chair-based interface (currently under development), and can grasp and release objects using the wand or a pair of pinch gloves.

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Signed communication with the virtual characters is accomplished through a basic gesture control system that allows for input and recognition of a limited number of ASL signs. A detailed description of the technical implementation of SMILE can be found in [3].

SMILE is being developed using an iterative user-centered design and evaluation approach, partially based on research by Gabbard and Hix [4]. The first evaluation cycle of SMILE produced key findings that have been used to modify and improve the design of the application. The object of this paper is the description of the second iteration and evaluation of SMILE. In this second implementation we: (1) combine elements of successful video game design (i.e., play, challenge, curiosity, and the presence of a rich metagame context) with current learning theories (i.e., constructivism [5] and constructionism [6]) in order to enhance user's motivation and fun, and (2) assess usability and fun through a formative evaluation with children.

In section 2 we discuss the benefits of virtual reality (VR) technology in education and the problems associated with existing VLE for children. In section 3 we describe SMILE game design and user interaction design; in section 4 we present the evaluation methodology and we discuss the results of the user study. Conclusive remarks and future work are included in section 5.

2 Background
Existing data suggest that VR technology can offer significant, positive support for education in general [7]. Although the benefits of VR experiences need to be defined in a more comprehensive way, recent studies show that VR often provides a more effective learning tool than traditional classroom practices and the experience is highly motivating [8]. Research also shows that VR is particularly suitable to math and science education because of its ability to 'bridge the gap between the concrete world of nature and the abstract world of concepts and models' [9]. This makes it a valuable alternative to the conventional study of math and science which requires students to develop understandings based on textual descriptions and 2D representations [10].

In regard to disabilities education, literature findings suggest that VR has advantages over other teaching technologies because it can fulfill the majority of the learning needs of students with disabilities including: access to safe and barrier-free scenarios for daily living tasks; control over environment; self-pacing; repetition; ability to see or feel items and processes in concrete terms; and motivation [11].

As far as children's conceptual learning, Roussou suggests that there are many compelling reasons for believing that VLE for children can provide effective educational tools [12]. However, due to the use of high-end expensive equipment and non-standard ways in which applications are developed, the majority of existing VLE for children are limited to academic and research environments, and institutions of informal education, such as museums. Furthermore, the majority of existing VLE for children have failed to achieve the ideal blend of educational and recreational value. This is a weakness of many educational tools which ‘have attempted to include the elements that characterize game design but have been unable to equal the appeal and excitement that computer games bring to children’ [12]. Until recently, research in VE has focused primarily on the technological aspects (i.e., visual quality and rendering efficiency) without much attention to content design and usability. As a result, many VLE are difficult to use and non-engaging [13], with user interaction limited to simple navigation and pick-and-place activities.

In an effort to improve on the current state-of-the-art, in this second iteration, we attempt to bridge the gap between tools for learning, such as educational software, and tools for fun, such as computer games, by creating an immersive application that is not a true game, yet remains engaging, is not a lesson, yet promotes learning.

3 Methods

3.1 Game Design

After the first cycle of evaluations we realized that while the children were able to perform the activities, they did not assume a role within the game, and therefore were not motivated to come back and play again. In order to enhance the fun of using SMILE we have researched the elements of video game design that promote engagement and motivation for continued play. Based on literature findings, as well as our own experience, we have defined a set of game design features which are likely to promote user’s interest and enjoyment, and, therefore, learning; these elements are summarized in table 1. In this second implementation of SMILE we have integrated these features with the three elements of intrinsic motivation (challenge, curiosity, and fantasy) identified by Malone and Lepper [14; 15].

GAME ELEMENTS THAT MAY PROMOTE ENGAGEMENT, MOTIVATION AND FUN	REFERENCE
A shared story context that establishes and support the activities (*metagame*)	[16; 17]
An overarching goal	[14; 16; 18]
A gentle on-ramp	[14; 16]
Multiple levels with variable difficulty	[14; 19]
Uncertain outcomes	[14]
No definite way to win	[17]
A well defined advancement system	[14;16; 17]
Rewards associated with advancement	[14; 16 ;17; 20]
Opportunities to build new content	[12; 16; 17]
Ability to progress at the user’s own rate	[17; 18]
Hints not answers	[18]

Table 1. Game elements that are likely to promote engagement, motivation and fun, and relative references

A *metagame* refers to a genre of play in which there is a clearly defined storyline and an overall structure that gives meaning and cohesion to all the game activities [16].

In this second iteration of SMILE, we have developed an overall story which is introduced through a cutout-style 2D animation at the beginning of the game. The story includes an overarching goal (restore the lost willingness to smile in the city of Smileville) which creates a boundary condition that unites the otherwise disparate activities. Each activity is in the form of a “good deed” whose objective is to make one of the Smileville characters smile again. All game activities are carried out in a *fantasy* virtual world. Malone argues that fantasy is the most important feature of computer games, and that fantasies should meet the emotional needs of the people who play the game. SMILE virtual world is represented in a visual style which is assumed to be appealing to the target age group: it is cartoon-like; Disney’s Toon-town [21] has been used as the main visual reference for the design of characters and environments. Key design features include basic geometric shapes with round edges, vibrant and varied colors, and a bright lighting setup with limited shading and soft shadows. The choice of the color and lighting schemes was based on research studies on the impact of color and light on learning [22] [23], and on the association between colors and children’s emotions [24]. One study shows that de-saturated colors have a negative impact on stimulation while highly saturated colors increase alpha waves in the brain which are directly linked to awareness. Another study reports that younger children (5 to 6 ½-years-old) are especially attracted to vibrant colors and most positive emotional responses are associated with warm colors. Research on the relationship between light and learning suggests that a bright lighting setup, with the presence of daylight, is associated with improved students’ performance [25]. The color palette and lighting scheme represented in figures 1 and 2 show adherence to these research findings.

Figure 1. A rendered shot of the city of “Smileville”

Figure 2. Bakery building, left; child in the FLEX interacting with objects in the bakery, right

In addition to being emotionally appealing, Carroll and Thomas [26] suggest that fantasy should also be used to ‘reframe’ information processing tasks to make them more interesting. In SMILE, all learning tasks are in the form of hands-on, goal- oriented, interactive activities. The attainment of the activity’s goal, as well as the outcome, is uncertain and dependent on the mastering of specific math/science skills, and on the construction of a new object. The activities are divided in three groups (or levels) corresponding to three grades (K-1, 2 and 3-- content for grades 4 and 5 is currently under development--). Upon successful completion of each task, the child advances her status by gaining rewards and virtual privileges (for instance the ability to tele-transport, fly, shrink, etc.). If the child is unable to complete an activity, the virtual characters can provide help in the form of hints. All instructions and help are spoken and/or signed. Hanna and Risden [27] argue that on-screen text should be avoided because children do not read text unless they absolutely have too.

According to Malone, another important characteristic of captivating games is the ability to evoke curiosity by providing an 'optimal level of informational complexity'. In other words, environments, characters, and activities should be novel and surprising but not completely incomprehensible, and should promote the users' desire to 'bring good form to knowledge structure' [14]. Although extremely stylized, with exaggerated and caricatured features, the majority of the objects and characters in SMILE are familiar to the children. However, the environment also includes 'mysterious devices' designed to evoke the children's curiosity and willingness to learn more. One example is the 'amazing baker's machine' (represented in fig. 3) which sets itself in motion when the children complete all the baking activities. During the formative evaluation with children, we noticed that the desire to see how the machine worked and what it produced (in other words, the desire to complete the knowledge of the baker's tools and devices) was the greatest incentive to finish all the math-based activities in the candy store and bakery. Furthermore, because the machine produces a different kind of pastry each time the child plays, it is also an incentive to come back and play again.

Figure 3. The baker's machine

In summary, our hypothesis is that (1) an intriguing story context that establishes and supports challenging tasks with variable difficulty level, (2) an emotionally appealing fantasy world designed to evoke curiosity, and (3) a well defined advancement and reward system centered on curriculum-based activities are all key elements that allow children to perceive their participation as meaningful and engaging and, thus, motivate them to continue to play and learn.

3.2 Interaction Design

In this second iteration we embrace both the 'constructivism' and 'constructionism' learning theories. The constructivist approach argues that learners must actively 'construct' knowledge by drawing it out of experiences that have meaning and importance to them [5]. A significant body of literature supports this learning approach: Dewey argues that education depends on action and Piaget believes that 'children develop cognitive structures through action and spontaneous activities' [28]. Papert further refines constructivism theory by focusing on the involvement of the student in the actual design and construction of 'external' artefacts [6]; he and his colleagues coined the word 'constructionism' to describe the knowledge construction process that arises from the physical creation of objects.

In order to enable these learning approaches in SMILE, we have extended user interaction beyond simple navigation and pick-and-place activities, and we have given the participant the opportunity to dynamically change the virtual world by building new content. To our knowledge, SMILE is the only VLE for deaf and hearing children, designed for formal education, including such a level of interaction.

Figure 4. Roby Robot, left; child in the clock store, center; clock store building, right

As mentioned previously, the overall goal of the game is to restore the lost ability to smile in Smileville and all game activities ('good deeds') contribute to this objective. The goal of each good deed is to make one of the people of Smileville smile again by giving him/her a meaningful new object. The ability to construct the object is dependent on the acquisition of specific math/science skills (and relative ASL signs). For instance, in one activity for first graders, the child is challenged with the task of building a new clock in order to make Roby Robot smile again (fig. 4 shows Roby Robot and one of the children performing the activity). This task requires the application of math skills (i.e., counting, recognizing shapes and colors, and adding) that can be acquired through a set of 'sub-activities' involving manipulation of objects and communication with the characters. Thus, the structure of SMILE includes two levels of interaction (and difficulty): at level 1 children acquire math/science skills; at level 2 they reinforce their knowledge acquisition by applying their skills toward the construction of an object. The activities in level 1 are exploratory and require primarily navigation and object selection/relocation; the activities in level 2 (object of this second iteration), lead to the construction of an object that did not exist previously in the virtual world. While at level 1 the child is a 'user' of the application, at level 2 she becomes 'creator' of new content. Our hypothesis is that active participation in the game, which means placing the user in a central active role with the ability to modify and create new objects, fosters engagement and motivation and, thus, learning.

Demos of SMILE are available for download at http://www2.tech.purdue.edu/cgt/i3/SMILE/demos.html .

4 Evaluation

4.1 Methodology

Usability evaluation of VE is still a fairly new area of research. However, a few researchers have started to recognize the importance of VE design and evaluation, and are keen on developing new effective assessment and design approaches. For example, Gabbard et al. [4] have proposed an iterative methodology for user–centered design and evaluation of VE user interaction, Bowman et al. [29] have presented a framework for the evaluation of travel methods, and Slater has focused on measure of presence [30].

The evaluation methodology of SMILE includes three forms of evaluation: expert panel-based, formative, and summative. The expert panel-based and formative evaluations focus on the design features of the application (i.e., usability and fun, quality of the visual representation, and quality of the signing motion), the summative evaluation tests learning and knowledge acquisition. The expert panel-based and formative evaluations are being repeated throughout the development of SMILE; their goal is to identify potential problems and produce recommendations to improve the design. The expert panel evaluation is carried out by a panel consisting of three experts in VR application development, two experts in 3D modeling and animation, and numerous experts in American Sign Language. Each evaluator is asked to perform an analytical assessment of the elements of the application that pertain to his/her area of expertise. The three experts in VR application development have so far assessed the usability of the program by determining what usability design guidelines it violates and supports. This has presented a challenge since clear heuristics for the ideal design of VE to guide usability evaluation do not exist yet. The set of usability design guidelines used by the experts was derived from previous work by [31] [32] [33].

The experts in 3D modeling and animation have been given questionnaires focusing on the quality of the visual representation of the virtual world; the experts in ASL have been given similar questionnaires relative to the quality of the signing motion. The evaluators have used a five point Likert scale for rating the response to each question, and comment boxes to provide additional feedback.

To date, several usability problems have been uncovered and solved; all elements of the visual representation and signing motion have been given high scores by the experts and, therefore, recommendations for improvement have not been necessary.

The formative evaluations with target users will be repeated at least three times before the summative evaluation takes place. In the next section we describe the second evaluation with children and we report the findings. Summative evaluation with kindergarten and elementary school aged deaf and hearing children will be done in collaboration with the Indiana School for the Deaf (ISD) in Indianapolis, and with two elementary schools in West Lafayette, IN. The children will interact with SMILE using a portable immersive system [2] consisting of a screen and frame, a high-end laptop, two commodity projectors, a pair of polarizing filters, inexpensive polarized glasses, and a tracking system.

4.2 Formative evaluation with children

The goal of the formative evaluation was to assess fun and usability of the second iteration of SMILE with a group of target users. The group of subjects included 21 children ages $6\frac{1}{2}$-10; 7 children are ASL signers. The minimum number of participants was determined using the Nielsen and Landauer formula [34] based on the probabilistic Poisson model:

$$\textbf{Uncovered problems} = N\,(1 - (1 - L)^{n})$$

Where: N is the total number of usability issues

L is the percentage of usability problems discovered when testing a single participant (the typical value is 31% when averaged across a large number of projects)

n is the number of subjects

Nielsen argues that, for web applications, 15 users would find all usability problems and 5 participants would reveal 80% of the usability findings. Lewis [34] supports Nielsen but notes that, for products with high usability, a sample of 10 or more participants is recommended. For this study it was determined that testing with 16 or more participants should provide meaningful results.

Usability of a game and fun of its use are two closely related concepts. According to the ISO 9241-11 definition, usability is derived from three independent measures: efficiency, effectiveness, and user satisfaction. Even if systems that are designed for children do not neatly fall into this usability paradigm, it has been postulated that fun is one manifestation of what adults call satisfaction [27]. Fun, however, is much more than a child's expression of satisfaction and, recently, a few researchers have attempted to better define and measure fun.

Our evaluation of fun is based on the three dimensions of fun proposed by [36]: expectations (i.e., the component of fun which derives from the difference between the predicted and reported experience), engagement, and endurability (or 'returnance', i.e., the desire to do again an activity that has been enjoyable). The evaluation methodology used to measure fun included: (1) *development of user task scenarios* (i.e., activities such as construction of new objects--we focused on the cake baking activity--, and sub-activities such as navigation and object selection/manipulation, (2) *ranking* and *rating exercises*, (3) *observation*, and (4) *think aloud protocol*.

Ranking and rating exercises were used primarily to measure endurability and expectations, while observation and think aloud protocol were used to assess engagement and usability. In general, ranking, rating, and observation have been proven to be more reliable than children's responses to questions on whether or not they liked something. Children are eager to please adults and may tell the evaluators that they liked the program just to make them happy [27]. All ranking and rating exercises were designed to be age appropriate: for instance, children rated activities and elements of the game using a scale with smiling and frowning faces. This scale, represented in fig. 5, is a discrete variation of the 'Funometer' proposed by [35].

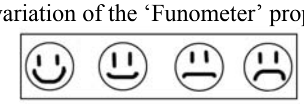

Figure 5. The pictorial rating scale

Research shows that children are able to respond more reliably to a pictorial representation with meaningful anchors (smiling and sad faces) rather than to a Likert-type scale [27].

In order to assess engagement, all testing sessions were recorded on video and the footage was scored with reference to a set of positive and negative instantiations. Positive instantiations that were looked for were smiles, laughing, signs of excitement (bouncing and throwing the arms up in the air), and positive vocalization. Negative instantiations were frowns, signs of boredom (yawns), signs of frustration (sighing and shrugs), and negative vocalization.

The usability evaluation included three commonly used evaluation techniques: (1) measurement of key usability factors such as *learning time*, *time to complete a task*, *number of errors* while performing a task, and *completion or non-completion* of a task; (2) *think aloud protocol* and '*critical incidents*', i.e., problems encountered that affect task flow and performance [4]; and (3) *observation*.

Since this evaluation focused exclusively on fun and usability, not on learning and knowledge acquisition, all participants were given a pre-test before the beginning of the interactive session. The objective of the pre-test was to ensure that all subjects had the basic mathematics skills necessary to complete the activities. The pre-test also included questions relative to the participant's expectations of the game, and questions pertaining familiarity with computer games.

The evaluation instrument including the pre-test and the rating/ranking exercises is available at: http://www2.tech.purdue.edu/cgt/i3/SMILE/demos.html

4.2.1 Findings

All subjects passed the pre-test (the mean was 23.3 out of 24) and therefore were able to proceed to the interactive testing session. The mean learning time, i.e., the mean time necessary to perform a sequence of basic operations (pick up an object, move it and place it inside another object, and then put it on top of another object) was 58 seconds. The mean time to complete the cake-baking activity was 5:26 seconds. 19 subjects were able to complete the activity on their first attempt, 1 subject completed it on her second attempt and 1 subject was unable to bring it to completion and was stopped on the 10 minute mark. Learning time and time to complete the cake were both considered satisfactory. The data comparison of mean learning times and task completion times with video game familiarity was inconclusive. No meaningful correlation between frequency with which children play video games video games and speed/ability to perform the SMILE activities was identified.

The diagram in figure 6 summarizes the results relative to the participants' expectations by showing the differences (in mean values) between the predicted and reported experience. According to Read et al. [36], this difference is an effective indicator of how enjoyable the experience has been. As mentioned previously, children rated their responses using the scale represented in fig. 5. To calculate the mean values, the happiest face was assigned a value equal to 4 and the saddest face was assigned a value equal to 1. Results show that the children had high expectations but the reported experience surpassed them. The game was perceived more fun and easier to use than expected, and slightly more challenging.

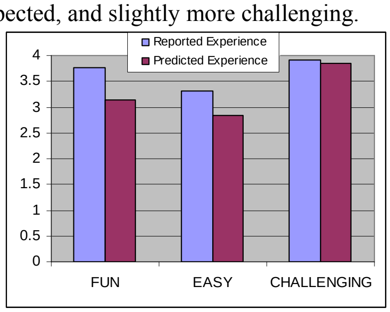

Figure 6. Diagram showing the differences between the predicted and reported experience

Table 2 summarizes the results of the 'Again-Again Table' used to measure 'returnance'. The table reveals that the activities the children enjoyed the most were the construction of the new object (i.e., the cake), watching the animated baker's machine, and playing the entire game.

Question	Mean (1-4)
Watch the beginning cartoon again?	3.21
Watch the ending cartoon again?	3.14
Make the cake again?	4.00
Explore the bakery room again?	3.71
Travel through town again?	3.92
Watch the amazing baker's machine in motion again?	4.00
Play the entire game again?	4.00

Table 2. Summary of results of the 'Again-Again Table'

Observation and think aloud protocol showed that other activities the participants found 'very fun' were 'walking through objects', 'throwing objects' ,'opening doors', and 'watching things that move'. As far as usability, children did not appear to have major difficulties with travel, selection, and manipulation tasks. We noticed a few signs of frustration and comments such as 'some of the ingredients are really hard to pick up' and 'the scale is hard to read'. Two subjects showed discomfort (dizziness and eye strain) with the head tracker and glasses and stopped interacting with the application after approximately 10 minutes. The main problem uncovered was the size of the 3D shutter glasses. Children kept loosing the goggles during interaction and were constantly adjusting them on their noses. The research team is currently researching different solutions such as using customized 3D glasses for children, or coupling the goggles with a head band.

As far as engagement, the majority of the subjects appeared to be very focused on the tasks. Positive comments included: 'this is awesome because you feel like you are really in a bakery'; '….this game is more exciting than a video game because you don't see anything around you… and you are really inside the building putting a cake in the oven'. Many positive signs were observed such as, laughing, smiling, bouncing in excitement, and 'wow' sounds.

5 Conclusion

This paper presents the implementation and evaluation of the second iteration of the SMILE project. In this second implementation we have improved the design of the game, enhanced the complexity of user interaction in order to make the application more motivating and appealing, and assessed usability and fun through a user study. The evaluations showed that, overall, the application is enjoyable and easy to use.

Though still at an early stage of development, SMILE can be considered the first bilingual immersive learning game for deaf and hearing children combining strategies from commercial video games with lessons from research on effective pedagogy, with the primary goal of making learning fun.

The learning outcomes of using SMILE have not been assessed yet. Future work involves production of additional content (for grades 4-5) and evaluation of learning and knowledge acquisition with children ages 5-10. The evaluation will start in Fall 2007 and will be carried out in collaboration with ISD (The Indiana School for the Deaf) and two elementary schools in West Lafayette, IN.

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