Next Generation Handheld Graphics Edutainment for Learning in Adaptive Student Centric Environments: Constraints and Benefits

Irene Cheng[1] Olenka Bilash[2] Walter F. Bischof[1] and A.Basu[1]

[1]Department of Computing Science, University of Alberta, Canada
[2]Department of Secondary Education, University of Alberta, Canada

Abstract
Graphics is being used as an effective tool in visual communication, e.g. Second Life, Google city scene and Microsoft scene reconstruction. It is already changing social, cultural, commercial and educational environments. 3D representations complement text and 2D images because they provide a depth perspective, enhancing user experience for understanding abstract and complex concepts, as well as inducing the feeling of immersion. These benefits have led to the adoption of 3D content in a game-like environment for educational and other applications. While main stream 3D technology has started to revolutionize the way content is captured and delivered to households (e.g., 3D Television, 3DTV, for entertainment), mobile 3D content is anticipated to emerge in parallel and be more and more pervasive in day-to-day life. Streamlined and cutting edge 3D content with increasingly rich semantics will soon be widely available on mobile devices. Keeping these emerging and fast growing technologies in mind, this paper focuses on investigating the constraints and benefits of handheld graphics in education, in particular on supporting curriculum designers and teachers to deliver high quality learning environment to users. We have implemented a handheld edutainment prototype system, which has been used as a test-bed by a group of teachers. From our evaluation we observe that while the education community can benefit from mobile graphics on handheld in a number of aspects, there are obvious constraints that prevent extension and immediate adoption of the technology in adaptive edutainment. We anticipate that developers will be able to design more effective student centric graphics edutainment learning systems on handheld devices by utilizing our findings.

Categories and Subject Descriptors (according to ACM CCS):
I.3.3 [Computer Graphics]: Distributed/Network Graphics—
K.3.1 [Computing Milieux]: Computes and Education—Computer Uses in Education K.3.2 [Computers and Education]: Self-assessment—

1. Introduction

Easily accessible mobile networks and affordable mobile devices have transformed visualization from the "desktop digital age" to the emerging "mobile digital age", which also suggests the possibility of migrating desktop applications to portable handheld devices. Early user interfaces on handheld displays were mainly text-based. Graphics initially supported only cartoon based games and screen savers with simple animations [KPu09]. With increased processing power of high-end mobile devices and the release of touch screens, together with web-browsing capability, graphics content on mobile handheld devices is becoming more appealing and realistic. Although mobile handheld technologies have been adopted in many applications available on affordable devices, e.g., text messages, emails, map navigations, games and web browsing; mobile edutainment in a real-time adaptive setting, targeting student modeling, has still not been adequately explored. Project Nokia.Expand aims to create a learning platform on mobile devices for children in developing countries [Afr11]. The potential of mobile learning was obvious when the project team found that students were really interested in exploring educational content on handheld devices. The deployment of mobile edutainment is anticipated to have a big impact in education, compara-

ble to the impact of mobile games in the entertainment industry. Furthermore, 3D graphics is an effective means for inspiring thinking, engagement and collaboration [CB09]. Rich semantics and abstract concepts can be presented using 3D content, which cannot be expressed by simply using traditional text and 2D images. The benefits of using interactive 3D graphics in education, especially in a role-play and game-like setting are discussed in several publications [CBG09] [CB08] [Che09]. The current trend is to transport 3D edutainment to a more mobile setting so that it is easily accessible to learners at a convenient time anywhere. In order to provide effective support for such development, it is important to understand the user preferences, as well as the constraints and benefits of adopting the technology to achieve satisfactory Quality of Experience (QoE). For this reason, this paper is not on the feasibility of how to make handheld 3D edutainment technically possible, but a study of the methodology that supports an adaptive client-server student centric edutainment environment and that provides learner satisfaction.

The remainder of this document is organized as follows: Section 2 discusses the opportunities and challenges of using graphics on handheld devices for adaptive learning. Section 3 introduces our hierarchical layered model. The implementation of a prototype is described and user feedback is analyzed. Section 4 suggests extensions, limitations and future trends, and Section 5 concludes with our research findings.

2. Opportunities, Challenges and Proposed Methodologies

Mobile phones are omnipresent. According to the International Telecommunications Union, in 2008 half of the world population used mobile phones. Nokia expected that by 2010/2011 there will be close to 4 billion mobile phone users [CPAM08]. It is thus beneficial to enrich their application content by incorporating appealing 3D graphics and to inspire learners in edutainment applications on mobile handheld devices. To achieve this goal, we must understand both human factors and technological constraints of these devices.

Why are Blackberries and iPhones so popular? They provide communication that relies on email and texting, either for business or social networking, and people want to use them anywhere and anytime. Surfing the web has also become inseparable from daily activities such that many users want it available away from their desktops and on their mobile phone. Google 3D City Scene was developed for desktops but it can become an excellent tool in learning if it is provided as edutainment content on mobile devices. Geographic information and Map navigation is becoming commonplace in vehicles and on handheld devices. 3D representations provide realism surpassing their 2D digital counterpart. The US National Park Service, for example, produces maps for 300 million annual visitors, transforming the use of maps from "reading" to "visualizing," i.e., maps are rendered on-the-fly on electronic devices with multiple layers of spatial data [Nur08]. In car navigation systems, content of GPS-driven maps can now be presented from the driver's viewpoint. Providing spatial information in 3D on mobile devices can not only facilitate learning at the fingertips but also improve understanding through high-quality visualization.

We understand from social behaviour studies that only one group of users always follow the norm or the latest technological fashion. A second group resist technological changes and limit their comfort zone to the status quo and therefore are unlikely to accept innovative ideas and try new technologies. A third group of users can be convinced to adopt new technologies by demonstrating the cost-benefits of adopting these technologies. In order to attract the last group of users, we need to have convincing evidence showing how individuals or society can benefit from edutainment. But for the second group, effective guidance and assistance is required to help overcome confidence barriers and to transit smoothly from previously familiar work patterns to innovative methodologies. When individuals feel that they are in control of a tool, adoption becomes easier and usage becomes routine. Once 3D edutainment is available on a larger scale on mobile devices, users can easily sense the improved engagement and immersion, which outperforms simple text and 2D image-based interaction. As soon as more users spread the word, and with some promotion, the majority will begin to follow the trend. A good example is the fast spread of "Brainage" by Nintendo after the manufacturer advertised its power of enhancing memory and brain power. Not only seniors but also teens started to play with "Brainage" as if it were a game.

While constraints on mobile devices, e.g., limited memory, battery life, processing power, and bandwidth have gradually been addressed, one major obstacle associated with handheld devices is their small display screen. One of our research goals is to study the impact of adopting 3D graphics and adaptive learning in handheld edutainment. Our target study group included teachers, who teach English as a second language (ESL). The target group was composed of international participants, and their feedback thus illustrates some cultural difference when assessing the use of handheld technology. In additional to language, e.g., English, we also discuss the feasibility of learning other subjects on handheld. To facilitate educational content population, we implemented an authoring tool which supports easy creation and upload of questions designed by teachers and curriculum designers. The strategy is to start by training teachers, curriculum designers and researchers in related disciplines, so that, as advocates for adaptive 3D multimedia edutainment on mobile devices, they feel competent to promote the technology to students and end-users. An important step to incorporate handheld learning into mainstream education is to introduce the mechanism to schools and uni-

versities [KHT05]. Our study uses the design of some prototyped items in our previously implemented online Multimedia Education Framework (http://crome.cs.ualberta.ca), in particular the drag-and-drop items, and retargets the layout to fit the small display on handheld devices. The research study focuses on benefits and challenges of adopting graphics edutainment items effectively on handheld devices, similar to the desktop implementations [SC00] [BC07]; and how to support an adaptive student centric environment, with the objective of achieving individualization and improving learning performance.

3. Edutainment Design on Handheld Devices

A desktop version of our Computer Reinforced Online Multimedia Education (CROME) framework was developed during 2006-2008. The learning items including 3D multimedia games have been evaluated by a number of users groups including high school students, university students and computing science researchers. In the context of edutainment, the term 3D refers to scenes not only in a virtual reality (VR) world but also in an augmented reality (AR) environment, where a virtual 3D character is embedded in a dynamic video scene (Figure 1) [CCB09]. While playing internet videos on a handheld is possible, incorporating videos effectively in a single real-time adaptive learning session with spontaneous client-server communications is still a challenging research problem.

Figure 1: *Augmented reality integrating a virtual 3D object (lion) with a dynamic video sequence (break dance).*

(a)　　　　　(b)

Figure 2: *Examples of CROME edutainment items on a desktop - (a) word puzzle, and (b) computing moment in Physics.*


Figure 3: *Simple question and answer is suitable for the small display area on handheld devices.*

The CROME edutainment items are designed for separate login sessions (Figure 2, but these discrete game items can be integrated as a sequence of related questions and presented to learners in a game setting. Due to the very different programming platforms between desktop and handheld devices, the Java applet game design cannot be migrated from CROME without conversion. A streamlined version of these items needed to be designed for mobile handheld devices. Also, due to the limited display area on handheld devices, a lot of the content intensive CROME items for desktops cannot be reused without simplification. Therefore, the design strategy for handheld devices should aim at simple and precise description of questions and easy expression of learner responses. Two examples of our designs are illustrated in Figure 3: (left) a spelling game, and (right) a number game.

However, simple edutainment design may not be creative and challenging enough for serious game players [KWJ*08]. Besides, subject knowledge is only one part of edutainment. To provide semantically rich coverage, edutainment items should also have the implicit power of describing cognitive and collaboration skills. The desktop versions of these items were implemented in CROME (left in Figure 4 and Figure 5), and a handheld prototype was also implemented (right in Figure 4 and Figure 5). Note that both the Visual-Spatial item and the Human Organs items are simulated in 3D. Overlapping and occluded components can easily be visualized by changing the viewing angle. Our preliminary study demonstrates that mobile edutainment on handheld can include more than simple text and 2D images. The challenge is how to establish a real-time adaptive client-server communications edutainment environment, targeting student modeling, and how to synchronize the handheld learning materials with classroom curriculum.

3.1. Model of an edutainment curriculum

To support student modeling, we propose a hierarchical layered model to incorporate "difficulty levels," which is consistent with the adaptive testing computational model described later in this paper. We chose ESL (English as a sec-
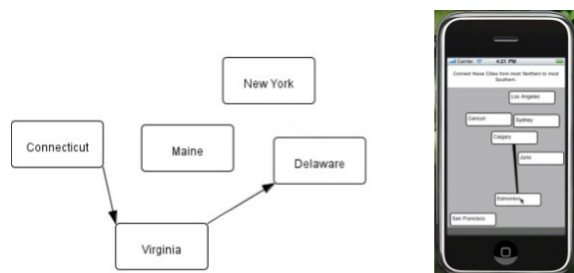
Figure 4: *The 3D CROME item (desktop version) for testing Visual-Spatial coordination is shown on the left, and the corresponding streamlined version on an iPhone is shown on the right.*

Figure 5: *The 3D CROME edutainment item (desktop version) for testing Human Organs is shown on the left, and the corresponding streamlined version on an iPhone is shown on the right.*

ond language) as our first target subject because of the availability of the target user study group, ESL teachers.

A major design challenge is continuity in content flow, as well as to keep learners motivated, especially for sophisticated game users. Movie-like stories with fast interactions between characters together with complimentary sound effect are often attractive to game players. Shooting and fighting are common dynamic interaction but they are too violent to many and can be male-centric. Our goal is to make the gameplay gender neutral. Cultural elements are introduced only if they improve learning performance of specific target groups. In essence, we model our gameplay to embrace a curriculum which has sufficient breadth and depth to cover a subject syllabus taught in classrooms. Based on the recommendations from experts in teaching ESL, we enforce clarity and appealing visuals, as well as offer encouragement (e.g., cue, bonus and praise). More importantly, the gameplay induces motivation through understanding and not memorizing answers in a static context. With these criteria in mind, we introduce a scaffolded sequencing hierarchical structure with Themes, Levels and Sets, to organize the ESL curriculum. The hierarchical layers are bound by association rules in both vertical and horizontal directions.
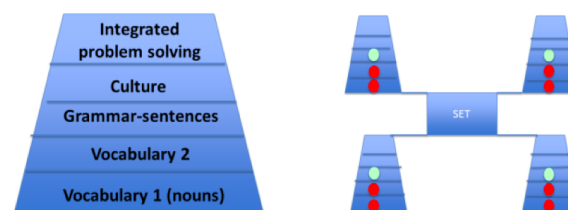
1. Theme

    a. A theme consists of levels. Each level contains multiple questions.
    b. Each consecutive level is worth more points.
    c. At the end of each level is a bonus question.
    d. The user must achieve a minimum score in order to progress to the next level.
    e. For the purpose of this ESL study, the levels address vocabulary (nouns, verbs, prepositions, adjectives, etc.), grammar, culture, and problem solving for 12-15 year old (but can be extended for other age groups).

2. Level (Figure 6 Left)-depth requirement
   In the test-bed implementation, a theme has five levels, each of which has a different focus. User must complete each level before progressing to the next.

3. Set (Figure 6 Right)-breadth requirement
   The user must complete a set in order to go onto the next set. The user must also complete several levels (red dots) in all four themes of the set in order to go onto the higher level (lighter dot) of any theme.

Figure 6: *(Left): There are multiple levels in a theme, and (Right): a set groups together with a number of consecutive levels in each of several themes.*

The goal of the game is to complete *S* sets and a bonus before proceeding to discover what "something" is, based on:

- A CLUE given by each set.
- All the clues leading to a DISCOVERY.

The student is given immediate feedback after each attempt and the student can gain points and some additional time if the answer is correct, but is not able to submit any more answers after time has expired. Figure 7 illustrates some steps to complete the game. First, (a) the student chooses a theme, e.g. School, House, Number and Body Parts, and start at Level 1; (b) after answering the given questions, a score is displayed and if the score is higher than the required minimum, the student is allowed to attempt Level 2. Higher levels are more difficult (c) and can be chosen from a different theme, as long as the Set constraint is satisfied. The student has to attempt all the themes belonging to the Set

and cannot advance to other levels of a theme outside the Set. This design tests both the student's depth and breadth of knowledge. Observe that learner-computer dialog and inter-activity are two main engagement factors in the design.

(a): Choose a theme. (b): A multiple choice question in the Home Theme.

(c): Level 2 is more difficult.
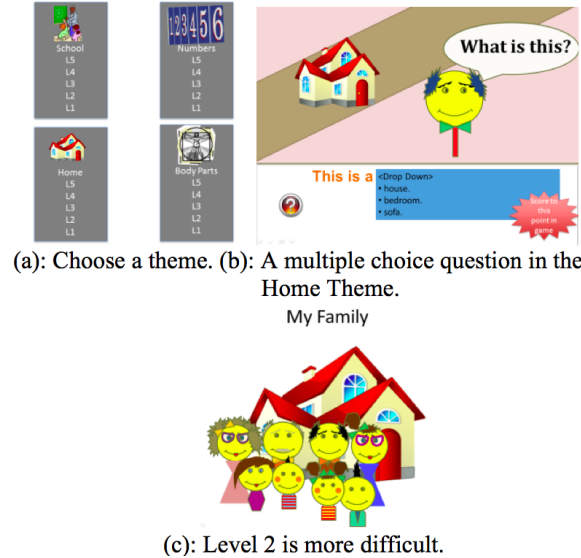
Figure 7: *An example of playing the ESL game.*

After successfully answering the questions, the student is assessed to have acquired the necessary knowledge to solve the puzzle. For example, the discovery of the criminal is based on understanding color and clothing (Figure 8).

Figure 8: *(Left): solving a puzzle, (Right) based on the knowledge of color and clothing, which are learnt from levels in a set.*

3.2. Student modeling and adaptive learning

Repeating the same questions to test the same or different students has many disadvantages:

1. The same student will feel bored when repeating a game. Eventual score may be due to memorization and not understanding.
2. Another student may obtain cues from friends and know the answers before playing.

3. Some students may feel frustrated because the questions are either too easy or too difficult.

Computer-adaptive testing (CAT) [Nce06] is adopted in our prototype system as a mechanism not only to support student modeling, but also to assist an educator's understanding of a student's ability and to provide suitable timely advice [CB09]. CAT divides questions of into groups of equal difficulty. The next test item is randomly selected from a chosen difficulty group based on the student's current score. The assessment principle follows the Item Response Theory (IRT), which is a family of mathematical models that describe how students interact with test items [LR97]. Regardless of the starting difficulty level given to a student, the student's ability can be assessed with a limited number of items as illustrated by the convergence rate of the curve shown in Figure 9. We apply the three- Parameter Logistic Model (PLM) in IRT:

$$P_i(\theta) = c_i + (1 - c_i)(1 + e^{-a_i(\theta - b_i)})^{-1},$$

where c_i is the guessing parameter denoting the probability of guessing correctly on this item; b_i is the difficulty parameter; and a_i is the discrimination parameter denoting how well this item can discriminate between students with slightly different abilities.

Figure 9: *A student's knowledge level based on IRT.*

3.3. Users preferences and proposed strategy

A group of eleven participants which included eight teachers from Japan visiting Alberta, Canada, was invited to play our ESL games, which were implemented on iPodTouch handheld devices (Figure 10). Ten of them had over seven years teaching experience, and most of them were between 36 to 45 years old. The group consisted of five males and six females. Five of them taught in high schools and six taught in middle schools. By reviewing their backgrounds, it is interesting to observe that irrespective of whether these teachers were trained in a traditional non-digital or a digital classroom environment, they all accepted mobile technology as a teaching mechanism and enjoyed playing the ESL games. They believed participating in this study had been a good opportunity for them to explore new ideas and promote the methodology to their peers and students. After the study, ten of them said they already had inspirations that could improve their current teaching style. In general, they were all
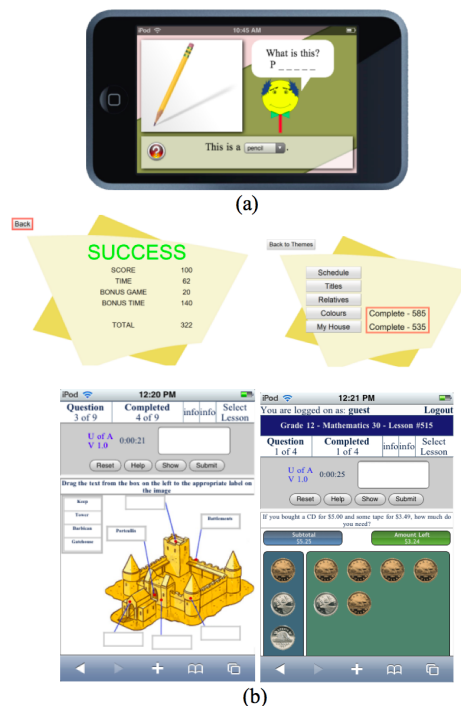
Figure 10: *(a) An iPodTouch handheld device displaying an ESL item, and (b) more examples of ESL questions, used in our mobile edutainment study.*

convinced that the hierarchical model would be of interest to their students. However, the test-bed questions were too easy and suitable only for ESL beginners. High school students could feel bored. Also, the questions could be more engaging if related to hobbies and daily activities, e.g. sport, TV, movie and transportation. The use of audio, animation, music, story and faster interactivity are also successful factors. Another helpful feedback is that they all felt the games were gender neutral; and interesting to both girls and boys.

Composing story (theme) as a sequence of events (levels)

(a) Choice of playing tools (b) Level 1: Smash ball

Figure 11: *Users prefer games associate with stories and daily life activities, e.g. sports, which can be used as the background for each level or each question.*

Based on the recommendations from the user study group we conclude that although the proposed hierarchical model is interesting, the content needs to be refined in order to induce motivation and engagement. Depending on the age group and the game playing skill of the students, appropriate themes should be designed. It is preferable to create a story for the subject questions and each level in a theme can be an episode of the story. For example, in the Set of "Culture," the Themes can be Sports, Tourist Attractions, Cuisine, Costume, etc.; and the Levels in a theme, e.g., Cuisine, can be drinks, appetizers, entrées, desserts and wines. After the Set requirement is fulfilled, the final discovery (similar to an exam) tests a student's knowledge provided in the levels and themes. To induce the feeling of continuity between levels and themes, the learner can be modeled as a athlete competing in various sports, or an explorer searching for treasures in different graphical scenes. As illustrated in Figure 11, the learner can be provided the option to choose playing tools (a) similar to playing sport in real life. Realistic images or graphical representations can be displayed as the level scenes, and the learner can enter different scenes at different levels in a theme (b).

Image upload and authoring tool

Since graphical content is essential and the adaptive student modeling approach needs to have a large graphics pool to support the numerous question at each difficulty level, our prototype system comes with an image upload and authoring tool to facilitate this process. Another advantage of having the image upload function is to allow teachers and instructors to change scenes easily to target their students' background.

Figure 12: *A time limit (indicated by the clock at the bottom right) is imposed on each game session.*

3.4. Client-Server Adaptive Communication Strategy

In order to reduce delay between answer submission and the next question selection, we transmit a random selection of five question items belonging to the same theme level to the client each time. The average score of the five answers is then used in the IRT computation. This average score is used as an index to retrieve the next five questions from the appropriate difficulty level bin for this particular student. A bonus question bin is associated with each difficulty level bin. Hint buttons are provided but the student loses marks by relying

on hints. A time limit (Figure 12) is also imposed on a session. Answering not enough questions within the specified time disqualifies the student from attempting higher levels.

Implementation platform

Mobile devices differ in the programming level because of hardware designs, and therefore implementing mobile applications, in particular those aiming at running across heterogeneous platforms, is challenging. We borrow from the experience in the CROME project implementation, but handheld specification calls for an interface that is so different from the CROME web interface that we cannot reuse the PHP code we have. The old database is too complex for the task - reusing it would significantly slow down the rendering. Javascript item types need to be rewritten to work well on handheld devices. Based on these considerations, our web applications are created using the Google Web Toolkit (GWT). GWT converts specially written Java code into HTML and Javascript web applications optimized for the major desktop and mobile web browsers. Compared with plain Javascript development, GWT provides great productivity benefits and helps us develop richer, higher quality software. The web service is a RESTful PHP layer between web applications and the MySQL database. Its purpose is to make sure that both web applications are communicating using clean, consistent concepts.

There are specific challenges in the creation of client-server architecture for a cross-platform mobile game. Running on mobile platforms entails the requirement for handling interruptions at any time, as a device can be turned off or switched to another application, suspending the game. The cross-platform requirement limits the available set of technologies. Targeting kids and people with little technical experience forces the game to be resilient against improper use. The content is also edited by teachers, who do not necessarily have much technical experience.

We chose to implement the game as a GWT AJAX web application, supporting the web browsers available on iPad players, as well as iPhone and Android cell phones. This restricts the available communication functionality to that provided by JavaScript. We chose to use the GWT Request-Builder class to communicate with our API service. Data parsing is done with JSON and JSNI, which is a natural choice for a GWT application, since it uses JavaScript's native functionality. In order to provide resilience against lost connections and misuse, we chose to use a RESTful style for our API. The client passes the user's credentials with each request to the server. Each request is performed atomically. As a result, the server is robust against any unusual usage patterns, such as game content being edited by several people at the same time or more than one person logged into the system under the same user account. It is guaranteed that the database remains consistent after any transaction, no matter what context it is executed in on the client.

4. Extension, Limitation and Future Trend

Extension

Although we used ESL in our prototype study, our adaptive mobile edutainment design can be applied to other subjects. For example, physics, engineering, nutrition and chemistry types of questions can be implemented as illustrated in Figure 13.
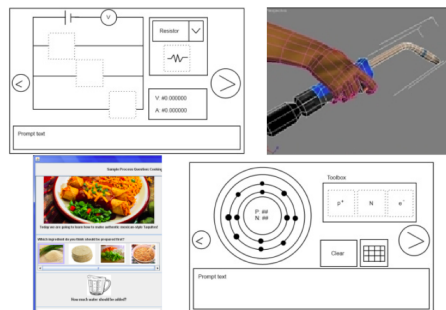
Figure 13: *Examples of Physics circuits, Engineering welding, Nutrition cooking and Chemistry questions used in a mobile edutainment environment.*

Limitation

In Table 1, we list the important features for the success of edutainment. However, not all of these features can be made available effectively in an online adaptive mobile environment. As shown in the last column, some features are already available (A), and some can be done (C) but may need to wait for further advancement in hardware and software platforms, while some will never be possible (N) due to the restrictions of display and keyboard size.

Audio effects such as sound and music, are as important as visual effects to keep the players motivated and engaged. Unfortunately, the current iPhone web-browser platform supports only simple single tone, and in the current implementation we are not able to include dialog and audio without initiating another browser, which will cause disruption to the learning session. Adaptive learning and testing type online applications, which require prompt communications between server and client, are restricted from utilizing many of the appealing features available to standalone mobile games, which can be downloaded and executed on the client throughout the gameplay.

Small screen size is a major concern for most handheld device users. A suitable device-independent color model [SSM11] needs to be adopted in order to make the content appearance appealing across heterogeneous handheld displays.

Future Trends

Mobile Internet access has been commonplace and successful in schools, and public places, but effective con-

Table 1: *Success factors of using handheld devices in adaptive online edutainment - (A) available, (C) can be done, and (N) not possible.*

Success factors of using handheld graphics in adaptive client-server student centric edutainment	
1-Large enough display/keyboard for manipulation	N
2-Embed audio/video in an adaptive client-server session	C
3-True 3DTV animation	C
4-High speed human-computer interactivity due to factor 1	N
5-Collaborative learning in a social media environment	C
6-Engaging gameplay design: storyboard approach	A
7-Adaptive learning and individualization	A
8-Progressive difficulty levels	A
9-Sufficient depth and breadth, and towards interdisciplinary content	C
10-Feasible cultural-specific add-on content	A
11-Gender neutral approach	A
12-Positive stimuli: Score, reward and praise	A
13-Hints and guidance	A
14-Synchronize the design with classroom curriculum	C

tent delivery on handheld devices, e.g., iPhone, still poses challenges due to hardware and visualization constraints. With the advancement of 3DTV technology on desktops and larger virtual reality displays, it will not be too long before stereoscopic and 3D images appear on smaller handheld displays. Stereo display can enhance visualization and understanding of complex and abstract concepts by incorporating depth cue. Students can study the 3D content and apply more critical thinking and analysis to a single display instead of rapidly switching between or touching on a sequence of displays. Research effort can also focus on providing a collaborative environment [Dom09] where students complete their team work in an adaptive edutainment environment, using text messages and social media tools on handheld devices.

5. Conclusion

Motivated by commonplace handheld devices, the effectiveness of adaptive student modeling, and the popularity of mobile games, we investigated the constraints and benefits of handheld graphics in education, in particular on how to synchronize classroom curriculum with adaptive mobile edutainment. We implemented a prototype system on an iPod Touch, which was tested by a group of teachers. We discussed various constraints and benefits of, as well as the emerging trends in adopting handheld 3D graphics. Our hierarchical layered student modeling design was well received by the study group, who will have access to the mobile edutainment items developed in this project and are free to use them in their teaching. We will be able to follow up with these users and collect further feedback regarding their and their students' experiences.

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