Adaptive Augmented Reality Serious Game to Foster Problem Solving Skills

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Abstract. This paper describes the design of an adaptive intelligent augmented reality serious game which aims to foster problem solving skills in young learners. Studies show that our students lack computational thinking skills in high school, which raises the need to establish new methods to develop these skills in our younger learners. We believe that problem solving skills are the fundamental skills of computational thinking and are critical for STEM, in addition to a broad range of other fields. Therefore we decided to focus on those meta-cognitive skills acquired to foster problem solving, such as strategic knowledge. The game described in this paper provides a unique adaptive learning environment that aims to develop learners' meta-cognitive skills by utilizing augmented reality technology, believable pedagogical agents and intelligent tutoring modules. It offers a great user experience and entertainment which we hope will encourage learners to invest more time in the learning process. This paper describes the architecture and design of the game from the viewpoint of educational pedagogies and frameworks for serious game design.

Keywords. Augmented reality, intelligent tutoring, believable agents, game design framework

Introduction

Problem solving is a cognitive skill that involves both analytical and creative skills and consists of using generic or ad hoc methods, in an orderly manner, for finding solutions to problems. Problem solving involves several metacognitive skills which refer to the active monitoring and consequent regulation and orchestration of those methods in relation to the cognitive object or data on which they bear [35]. One fundamental metacognitive skill related to problem solving is strategic knowledge (conditional knowledge) which is one's own capability for using strategies to learn information. Developing these metacognitive skills fosters student's problem solving skills and accordingly their learning and academic achievement. This is one challenge our young students face as they are not particularly good at this; it might take them until upper elementary to develop the understanding of strategies that will be effective. It should be pointed out that an ordinary person almost never approaches a problem systematically and exhaustively unless specifically educated to do so [35].

No one achieves a high level performance in any domain without a great investment of time [1]. Therefore, developing problem solving, as well as any other skill, requires training. Technology can be considered a catalyst for teaching and learning that can

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help in engaging the learner for longer periods of times and can help in promoting positive educational change [2]. Engaging the learner in a dynamic process that provides visual and interactive forms of authentic learning has been rigorously researched in the past few decades. Big challenges usually appear when it comes to developing cognitive and meta-cognitive skills because of their ill-defined nature. Ill-defined domains are characterized by their blurred boundaries and inexplicit answers to the problems that exist in these domains. In other words, there are no well-known, universally agreed steps we can use to develop cognitive skills. Developing such skills requires investment of time and lots of practice.

Although Intelligent tutoring systems (ITSs) have proven to be effective in engaging learners and providing personalized learning process through the use of a student model [3-8], there are a number of missing elements that seem necessary to stimulate desired learning outcomes, such as narrative context, rules, goals, rewards, and multisensory cues [1]. Serious games evolved as a field that combines education with game aspects which allows learning to be more motivating and appealing [9]. Serious games are games that incorporate the entertaining format of a game in order to accomplish educational goals. Serious games have proven to be engaging in ways that do not only keep students playing the game, but also keep them interacting with the game in a way that creates real learning experiences and help them achieve subject matter goals [10-16]. Serious games use 2D virtual environments, and non-playing characters to engage the learners and guide them through the learning process to help them achieve the desired learning outcomes. Although results are satisfactory, researchers always look for new and creative alternatives that can provide higher engagement and new educational pedagogies or a blend of existing pedagogies.

One important result researchers seek to measure in regards to educational games is transfer. Researchers measure transfer by focusing on extended performances where students "learn how to learn" in a rich environment and then solve related problems in real-world contexts [17]. One of the major criticisms of instruction today is the low rate of far-transfer generated by presentational instruction. Even students who excel in educational settings often are unable to apply what they have learned to similar real-world contexts. We do believe that the use of a new technology such as augmented reality can facilitate the transfer process. Although, augmented reality is expected to affect higher education soon [18], we believe that it could have high impact on primary education too.

Although augmented reality (AR) is not new, its application in education is just beginning to be explored. Augmented reality is a live, indirect view of a physical, real-world environment whose elements are augmented by computer-generated sensory input such as sound, video, graphics or GPS data. AR is learner based, allowing the learner to direct their course of discovery in a rich environment that allows for experimentation and making mistakes with no major consequences. Most of the current research and discussion about AR in education focuses on what are the emerging trends, how can they be used in learning settings and what affordance can they offer as well as their limitations. There is little research at this moment related to program design and how AR can be integrated into or change our current approaches to learning and education. This raises the need for further research in this area to develop a model that can serve educational needs.

This work presents a new educational platform that integrates augmented reality and intelligent tutoring to foster problem solving skills at k-5 students through developing their strategic learning. This can be attained through hands on activities and adaptive learning process in a rich interactive environment.

1. Augmented Reality in Education

In the field of education, AR applications have to be grounded in sound pedagogy. Further research is still needed to highlight its relevance and what enhancements AR will bring to the student learning experience. Certainly AR is simpler to use than virtual technology which may make it easier to bring into the classroom if desired. The fact that AR layers information onto the real world may make this type of digital technology more acceptable for those concerned about the use of virtual technology [32]. Most importantly, AR allows for the seamless integration between the real world and the virtual world, which can be a valuable thing when it comes to merging the child's real life with the presented virtual environment. We think this particular point will benefit the teaching pedagogy adopted in this work.

AR has been found to facilitate spatial learning particularly for those who are challenged in translating concepts from 2D to 3D [33]. Another affordance of AR is the concept of "sense of presence" or "embodiment" when using AR in a learning context. That is, participants have an actual experience and remember it as an actual event thus making connections to previous knowledge stronger. For these reasons, AR has been found to be a plausible platform for educational systems. Few AR games in education have been developed in the past few years. An AR historical game for students to learn about the American Revolution was developed in which GPS data that triggers events in players hand held devices was used [19]. The game takes place at the Battle of Lexington in Massachusetts. The players are assigned various roles and sides in the battle and are able to interact with historic characters. In the process of playing the game the players use the experience to understand the battle. The results suggest that AR games can potentially teach 21st Century skills such as interpretation, multimodal thinking, problem solving, information management, teamwork, flexibility, civic engagement and acceptance of diverse perspectives [19]. In 2009, believable agents were used in a head-mounted visualization training system that combines real world views, computer generated images and avatars [35]. Soldiers interact in a realistic training environment with their own weapon, while interacting with computer-generated avatars. The avatar responds realistically to the soldier's actions by talking, avoiding contact or returning fire.

Google Sky Map is another popular educational augmented reality application for the Android platform. Google Sky Map aims to teach astronomy concepts using geolocation to superimpose the constellations and other sky objects that are present in the sky above (or below) wherever you point the phone or tablet. Although the app could be used by teachers or parents for collaborative inquiry or in activities accompanying direct instruction, but the game lacks interactivity, learning support module(s) and consequently adaptation. Similar applications for Android include colAR, AR Flashcards, and Spacecraft 3D.

colAR is an AR app that allows users to print pages from the website, color them and then use the app to bring their colorings to life with augmented reality. However, the app incorporates no gameplay, tutoring component or pedagogical agent. Although it is easy to see how this app could be extended to incorporate literacy or even science and social studies components, at this time the color page choices are limited and the app is mostly entertaining. AR Flashcards is an augmented reality application for young children. Users download and print the flash card sets from the website and use the app to view a three dimensional representation of the card. Although this app has no gameplay or instruction, the flashcard concept could easily be expanded to other topics and age groups. Spacecraft 3D is an augmented reality application from NASA that allows users to view the various spacecraft used to explore space. Users print out the AR spacecraft target and then choose the spacecraft they would like to view. There is no interactivity, instruction, or game play associated with this app.

Two AR games for mobile devices that do include interactivity and gameplay are Fetch! Lunch Rush from PBS Kids and a game currently under development at the Georgia Institute of Technology called Monster Plus. Fetch! Lunch Rush is an addition and subtraction AR game with a tutoring component, but it is only available on the IOS platform [20]. Fetch! Lunch Rush displays an equation and three answers, each with its own marker. Users put their device over their answer. If they are correct they get sushi, if they miss they get a hint and another chance.

Monster Plus is a game app currently in development [20]. It features a monster that lives on an island surrounded by boat docks. A number is displayed to the user depicting how many food items the hungry monster would like to eat. The boats have different numbers of items and the user has to choose the correct combination of boats that will add up to the number of food items. The board and cards representing the boats must be printed. The augmented reality displays the monster, the number of needed food items and the food items in each boat. Although Fetch! Lunch Rush provides hints and various difficulty levels, it does not provide personalized learning experiences, and neither does Monster Plus.

To the extent of our knowledge, there is currently no existing AR games in education that incorporates interactive engaging tasks, teaching pedagogies and adaptive learning processes. We hope to address this lack with our game and add believable pedagogical agents in hopes of increasing student motivation to interact with and learn from the game in addition to providing implicit teaching and an immersive environment. Adaptation allows tracking player performance through employing a student model and providing challenging activities in the student's zone of proximal development in order to maximize learning.

Lester and Stone relate that "believability in animated agents is a product of two forces: the visual qualities of the agent, and the computational properties of the sequencing engine that schedules its behaviors in response to evolving interactions with the user" [17]. The use of augmented reality and believable agent seeks to improve visual quality by integrating the virtual world as well as the virtual characters into the real world of the player. In this paper, we describe an augmented reality serious game that provides personalized learning experiences to the players and can be used on mobile devices running the Android platform.

2. Pedagogical believable agents

Pedagogical agents are computer characters capable of exhibiting aspects of intelligence that fulfill pedagogical purposes by guiding learners through the learning environment. The implementation of agents within the game should increase the player's engagement and contribute to several elements that have been shown to increase student motivation in learning with educational games. A pedagogical agent can contribute to the narrative context, communicate goals, provide rewards and increase interactivity. Most importantly, pedagogical agents allows implicit (weaved into the background story) and explicit feedback and scaffolding which are essential for student learning.

Creating a believable pedagogical agent should further enhance the student experience of these motivational design elements. Lester and Stone define "believability" as "the extent to which users interacting with an agent come to believe that they are observing a sentient being with its own beliefs, desires, and personality" [21]. They go further to note that "increasing believability will yield significant rewards in student motivation as they interact with learning environments" by providing engaging social interaction that is in itself motivating. They mention observational studies they conducted with middle school students which showed that students' interest in learning was greatly increased by an agent's life-like presence [21]. Learning support provided by a believable pedagogical agent such as feedback and scaffolding should be gauged as more useful and believable by the learner further increasing learning gains.

Agents that perform pedagogical roles have been explored in serious games [16]. Some of the characteristics that should be considered in any believable agent include: personality, emotion, self-motivation, change, social relationships, consistency of expression, and the illusion of life. The illusion of life is one feature that can be accomplished by the appearance of goals, the concurrent pursuit of goals and parallel action, the ability to react and respond to an appropriate situation and existence in a context, being resource-bounded, broad capability, and proper integration of their capabilities and behaviors [22]. In addition, a believable agent must be believable within the context of the activities presented. Care must be taken not to create expectations by the learner that the agent cannot fulfill. Furthermore, the interaction with the agent should enhance the learning process and not distract from it. Accordingly, we created our agent with the illusion of life, ability to react and respond, ability to have social relationship (be a friend to the player), and able to provide personalized tutoring in the context of the background story of the game.

3. Current work

Both the learners' motivation and engagement depend to a large degree on "immersion." Immersion is the subjective impression that one is participating in a comprehensive, realistic experience [23]. In this case, the learner has to have a "sense" that he or she has an important role in the educational work at hand. The learner would be more motivated and engaged to complete a task knowing that his or her actions would have consequences in the world they are engaging in. By adding in Pedagogical agents, the learner's immersion would be heightened by the responses from the agent. This can assist in increasing the motivation and engagement of the learner.

The current work involves creating an augmented reality serious game that incorporates a believable agent in order to increase student engagement in the activities in a meaningful way that promotes learning and the development of mathematical problem solving skills. The student will initially be engaged via a narrative that places him or her in the position of the helping the characters that will also act as pedagogical agents within the game. Several believable agents will be introduced, each with a distinct teaching/learning style (e.g. fast-paced/competitive, cooperative, independent learning). After the initial introduction to the agents and initial assessment of the student level with some pre-assessment activities, the student will be able to choose the agent he or she prefers to continue learning with which will then dictate the learning style of activities for the rest of the game. The following subsections describe the game architecture and the rationale behind the current design.

3.1. Overall architecture

The proposed game aims to provide an engaging personalized learning experience to the players in a rich interactive environment. Dunleavy et al., (2009) provide a diagrammatic conceptual framework for the process of AR in the learning environment [17]. In the presented architecture, Dunleavy et al. incorporated the teacher as the facilitator of the learning experience, which provides the challenge in which the teacher has to manage the overhead that accompanies AR simulation implementation. The high management requirement suggests that providing teachers with adequate support for implementation is crucial. Many teachers have 25 or more students in a class, making it difficult to manage complex activities involving critical thinking tasks. Substituting the human teacher in this model with an intelligent tutor seems an intriguing idea because of the success of this paradigm in intelligent tutoring systems and serious games in the literature as well as because of the feasibility it can provide to the proposed model for classroom use. For this reason, we decided to adopt Dunleavy et al. model and adapt it to serve our needs, see Figure1.

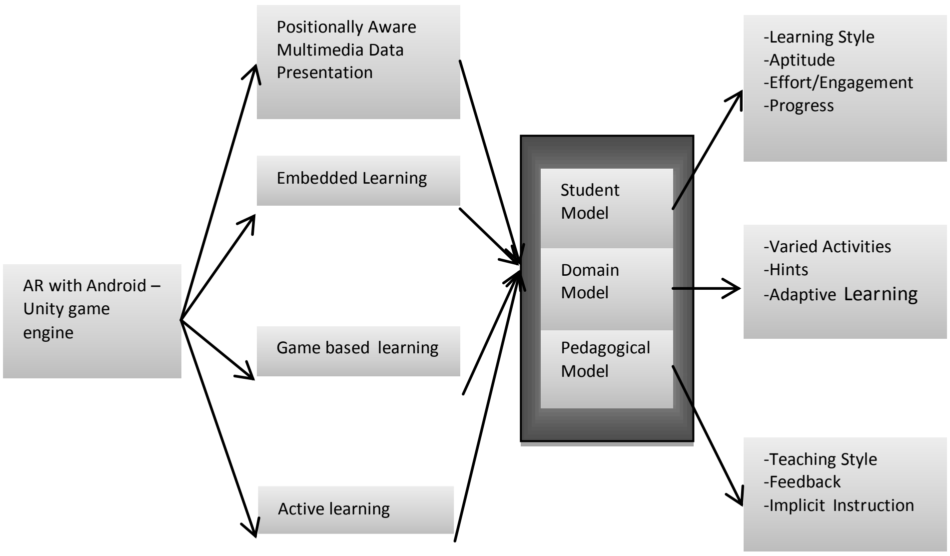

Figure 1. The architecture of AmonPlanet Game

The architecture utilizes multimedia presentation, active learning, game based learning and pedagogical techniques in order to maximize student learning. These work together through the interactive nature of the game play requiring active participation by the user in a context dependent task that helps develop strategic knowledge and mathematical thinking presented through multimedia technology. Knowledge is embedded in the setting in which it is used; learning involves mastering authentic tasks in meaningful, realistic situations [24]. As learning through immersive interfaces is important in part because of the crucial issue of transfer [25], the mixed environment provided by AR and the real world is expected to create novel and task-specific understandings which should facilitate the transfer of knowledge.

Embedded learning gives context to abstract skills. We plan to incorporate intelligent tutoring modules into the game in order to add independence to student learning that does not require a large input of adult assistance. Studies have shown that young children require support for learning until they gain a sufficient knowledge base for independent learning [26]. In our game, the game itself, through the intelligent tutoring components, provides the necessary scaffolding essential for real knowledge acquisition.

The architecture involves the interaction between a student model, a domain model and a pedagogical model. The student model will hold student information about the student's learning style and ability level as well as information about current effort and engagement with the game and progression through the levels. The domain model will hold varied activities, hints and other elements of adaptivity that can be chosen during gameplay in response to information in the student model. The pedagogical model will hold variations in teaching style, feedback and ways of varying implicit instruction capabilities that can be modified in response to the student model.

3.2. Design of the system

AmonPlanet is an AR serious game that has a background story and engaging tasks that should motivate and immerse the players and encourage them to spend long periods of time playing and exploring the game world. All the tasks provided in the AmonPlanet world are sewed into the background story. The game employs a student model that helps provide an adaptive learning tailored to each individual player's skills via tracking and assessing the player's actions and providing him/her with the tutoring appropriate to the player's current skills. Providing the right level of tutoring encourages the player to spend more time playing the game and accordingly should help increase his practice. One of the most straight forward effects of increased practice is that tasks are performed more quickly and more accurately [27]. The game also contains a pedagogical model that present the tasks in a way that helps the student to acquire simple units (skills) that form the basis for developing other complex skills, which has proven to be a successful teaching strategy [27].

AmonPanet allows learning to take place in the player's real environment. This is made possible by the implementation of augmented reality which literally brings the characters into the player's world. The background story in AmonPlanet starts with an invasion to a planet inhabited by Zeomons (aliens) by the smart viscous creatures, the Bigaliens. Several of the Zeomons managed to escape the invasion to seek help from planet earth. As these pedagogical Zeomon agents landed on the player's back yard, Bigaliens followed, trying to capture them and posing a challenge to the player. All parties agreed that the only way to solve this dilemma is by making the player attend a universal intellectual competition and letting the Zeomon train the player toget him prepared. A series of activities should be provided in this mode to make the player get emotionally attached to the Zeomons. In the following are examples of the activities/tasks provided in the environment.

In order for the learner to understand that fractions can be represented as a subset, the learner will be presented with a fraction and a number of food items. To fulfill this task the pedagogical agent will ask the learner to bring his favorite toy to the game. The game captures the toy and allows it to be part of the virtual world, see Figure 2a. The learner will be asked to share a fraction of the sweets (for example, 3/8 sweets) with his favorite toy, see Figure 2b. The learner must click 3 of the 8 pieces of candy to share with the toy. Once the learner finished the task, he/she presses the GO! button and a visual animated feedback is provided. For example, if the answer is correct, the toy can give the player a balloon or jump up and down or fireworks will appear (positive feedback). If the answer is wrong, the sweets jump back to the original positions indicating the player has to try again (negative feedback).

When it comes to young children, we all know how children are attracted and attached to their toys. So, bringing the learner's real toys to the virtual world should increase the player's motivation and engagement in the game. Another task would involve asking the learner to choose their own fraction to represent part of the displayed set and then choose the appropriate number of items.

When the student has mastered the concepts through playing the required tasks, the narrative will begin again and the game will be taken to another "world" where the student will have a final assessment "competition" in order to "save" the pedagogical agents' world (AmonPlanet). Future mathematical modules can be added that would take the student with his new friend and tutor to other worlds for learning.

(a) **(b)** **(c)**

Figure2. Snapshots of AmonPlanet Game

Figure 2 shows the interface for this project is analogous to that of a video game. Since the intended age group is between K-5 grade levels, use of images, 3D models, and large text will be used. Children in this group tend to be visual learners, they learn better when seeing actual objects illustrate abstract ideas. Simple text will appear on the screen indicating the current task and will change based on input from the learner. 3D objects used to facilitate answers can be manipulated by touching the model on the touch screen. For example, the learner is tasked with a fraction question where he/she has to tap on candy pieces until the right amount is reached. The learner has to then tap on a 3d button in the augmented world to complete the answer. The wrong answer will prompt a text to "try again" until a right answer is reached. Upon a correct answer, a prompt will appear on the screen indicating a job well done as well as starting up a new question. In essence, the text is secondary to the 3D objects in terms of importance. This approach will take advantage of the visual learning traits of the learners and deliver content in a visual friendly manner.

4. Game Aspects in AmonPlanet

In 2004 Gee published a list of learning principles that should be included in good serious computer and video games [4]. According to Gee, the more features integrated into the game, the more effective the game for learning. The following sections describe how elements of Gee's list will be accomplished in Amon Planet.

4.1 Empowered learners

4.1.1 Co-Design

Co-Design refers to the level with which students believe they exert some control over the game. In Amon Planet the student can bring in and change their toy companion. However, other than this, the students are limited to the tasks and story line presented.

4.1.2 Customize

This principle refers to the capability the student has within the game to select options for changing the game to fit his or her learning needs. In Amon planet we present several pedagogical agents, each with a different learning style. Once all have been presented, the student will be able to choose to continue training with his or her preferred agent and learning style.

4.1.3 Identity

The identity principle is the degree with which the student becomes immersed in the game by taking on a different identity. Amon planet does not offer the option of taking on entirely new identity, but it does allow the user to play the hero role for a group of aliens who need help saving their planet.

4.1.4 Manipulation and Distributed Knowledge

Games that allow detailed manipulation of the characters create a more immersive and compelling game environment. Future levels that take place on other worlds may offer options for exploration and more detailed manipulation of the game environment.

4.2 Problem Solving

4.2.1 Well-ordered Problems

Adequate scaffolding requires problem difficulty to increase at a level that keeps the student within the zone of proximal development. Amon Planet utilizes an intelligent tutoring system that adapts to the student's level by changing the problem difficulty and by offering hints when needed or requested.

4.2.2 Pleasantly Frustrating

Students will only stay involved in a game that provides a challenge in a way that compels them to solve the challenge. Amon Planet accomplishes this through believable pedagogical agents that provide feedback and encouragement. In addition, Amon Planet utilizes implicit rather than direct instruction which requires the student to learn by doing, through trial and error.

4.2.3 Cycles of Expertise; Skills as Strategies

Expertise is achieved by practicing skills to the point of automaticity and then failing in a way that creates the cognitive dissonance that facilitates genuine learning. By utilizing implicit learning we can present tasks the student has to solve through their own experimentation. Once they succeed several times and begin to create a template for solving a problem type, they will be presented with an example that does not match the previous template. They will then have to create a new template. For example, when presented with part of set problems initially, the fraction presented will have the denominator matching the number of items, e.g. share 5/8 of 8 candies. Once they can easily solve these problems, they will be presented with problems where the denominator does not match the number of items, e.g. share ½ of 8 candies.

4.2.4 Information On-Demand and Just-In-Time

Few players read instruction manuals, so good games provide enough information within the game to allow students to navigate the game efficiently. Amon Planet provides a narrative introduction and a simple interface with available hints to get students playing quickly and easily.

4.2.5 Fish Tanks; Sandboxes

Fish tanks and sandboxes are side games (mini games within the main game) that allow the student to practice and receive tutoring. Amon Planet does not provide these explicitly, however the training tasks are designed to allow the student plenty of low-risk practice with more rigorous challenges at the end of each training session and a boss level challenge with Bigaliens at the end of the game.

4.2.6 Skills as Strategies

People have a strong preference for practicing skills within a meaningful context. Amon Planet tries to provide this by allowing the student to "feed" their toy in practice and having practice tasks build to a mini challenge at the end of each training session.

4.3 Understanding

4.3.1 System Thinking

People learn best when the learning is fit into an overall, meaningful larger system and an understanding is fostered such that the new learning can be used for setting personal goals and taking action. Amon Planet uses believable pedagogical agent to help students think about how the fraction concepts they are learning can be applied to real world situations. The mini-challenges utilize real world applications of fractions such as measuring and cooking.

4.3.2 Meaning as Action Image

Humans construct meaning through experience much more strongly than through abstract learning of definitions and logical principles. Games have the potential to create meaningful learning if concepts and words are tied to the real world actions. Amon Planet seeks to achieve this through the toy brought into the game world via augmented reality as well as through mini-challenges that tie in real world problem solving with fractions.

5. Discussion

Problem solving is an important cognitive skill that highly impinges on other cognitive skills, such as computational thinking. Studies have shown that high school students in the US have lower computational thinking skills than their peers in other countries [30]. The study suggested that developing such skill should start as early as elementary schooling years. This can be achieved through engaging educational platforms/environments that can train and educate students about those metacognitive skills which have direct impact on other complex cognitive skills such as problem solving and computational thinking. Augmented reality is one technology that can provide fun, safe environments in which student can practice and develop these cognitive and meta-cognitive skills.

Augmented reality has plenty of options when it comes to functioning in educational environments. Object recognition, geotagging, virtual input, and media effects are a few of the tools a developer can utilize to craft a unique interactive educational experience. In essence there is no limit as far as to the variety of environments that can be used to craft interactive educational experiences. Another motivation for using AR in education is the ease of using them on Android devices which are relatively inexpensive, portable, can be used in a variety of contexts and are readily available.

This paper presents AmonPlanet, an intelligent AR serious game that integrates augmented reality technology and intelligent tutoring modules to foster strategic knowledge in young learners. The game world is inhabited with pedagogical believable agents that help motivate and engage the learner as well as provide individualized learning experience. The environment presents the learner with challenging tasks that are weaved into the background story. To increase the learner's engagement and motivation, the tasks in the game are designed with learning theories of Gagné and Keller in mind [28, 29]; AmonPlanet allows the learner to bring in their favorite toys to be part of the game and share the game activities with them. The game design considers different game aspects as mentioned earlier in the paper which should help the player spend long periods of time playing the game which is one key factor for fostering the development of problem solving skills, in addition to providing a personalized learning experience through the use of intelligent tutoring modules. Future plans include finishing the prototype and evaluating the game through focus groups.

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