Swarm Intelligence Framework for Tutoring

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Abstract
A web-based intelligent tutoring system with some swarm intelligence capabilities and with the integration of a learning units with Adaptive Augmented Reality Serious Games (AARGS) is presented. Adaptation to the children, necessary for a more effective learning experience is achieved through two means: the use of sequencing graphs and swarm intelligence techniques. Sequencing graphs determine which paths are available for the children. Successful paths traversed by children are reinforced in the graph. This information is presented to the children every time they finish a *learning unit*, so they can choose next units with some information about how their peers did perform in the same situation. The mechanisms of stigmergy (inexplicit, mystical process by which ants and other social insects can create highly complex physical, social and communication structures without any apparent central planning or organization) will lead to the appearance of optimum learning paths. each *learning unit* presents a new educational platform that integrates augmented reality and intelligent tutoring to foster problem solving skills at k-6 to k-12 children through developing their strategic learning. This can be attained through hands on activities and adaptive learning process in a rich interactive environment.

Keywords: Swarm intelligence, web-based intelligent tutoring system, Augmented Reality, Serious Games, Plain graph, Sequencing graphs

Web based education

Web based education (WBE) is becoming more popular in recent years, as many learning activities are moving to the web. One of the main challenges of web-based system is their ability to be adaptive, i.e. to adapt to different user requirements. A web based tutoring system may offer customization and an adaptive personal environment for the learner [39], thus avoiding the "lost in cyberspace" problem [44]. The existence of a tutoring guide for the learner maximizes the effectiveness of the learning process [36]. This paper presents a web-based tutoring system that adapts the sequencing of a set of learning units to the children capabilities and needs. It is based on [45], but proposes a complementary approach to obtain better results.

The work in [45] is based on hierarchical graphs, which are a particular case of the finite automata paradigm. The graphs define transitions between different learning units based on some parameters. These parameters are a function of the actions of the learner and its past history in the system. Once the graph is designed, the system can automatically adapt the sequence of learning units to different learner needs, taking more time to explain some concepts that the child finds difficult or skipping aspects over which the child has great knowledge. This adaptation is achieved following different paths in a hierarchical graph, depending on the child's actions.

We propose a way to extend this idea, based on swarm intelligence techniques. Our approach has some similarities with other swarm-based web-based educative systems and takes some ideas from the collaborative filtering field. The paths that the children take along the graphs are recorded and analyzed, so good paths are reinforced and bad paths (i.e. those leading to poor or no learning, bad result on assessments, etc) are penalized. That way, the children themselves find the best *learning paths* along the graph presented to them, in a distributed and automatic way.

The Learning Unit

Intelligent tutoring systems (ITSs) have proven to be effective in engaging learners and providing personalized learning process through the use of a child model, 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 [36]. Serious games evolved as a field that combines education with game aspects which allows learning to be more motivating and appealing [44]. 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 children 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. 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.

One important result researchers seek to measure in regards to educational games is transfer. Researchers measure transfer by focusing on extended performances where children "learn how to learn" in a rich environment and then solve related problems in real-world contexts [17].

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.

Collaborative Filter In N Dimensions

Our approach gives the children the opportunity to see what are the 'reinforcements' on each arc. This bears similarities with collaborative-filtering applications, CoFIND (Collaborative Filter In N Dimensions). CoFIND's purpose is to replace the role of a traditional teacher in structuring and selecting learning resources. It attempts to achieve this through a process of stigmergy and natural selection, leading to a degree of self-organization brought about through the independent actions and interactions of its individual users.

In that case, children had to select between educational resources giving more weight to the more useful ones. There was no sequencing involved, just a distributed filtering of the most valuable resources (e.g. web pages, multimedia presentations, etc) from the point of view of the children.

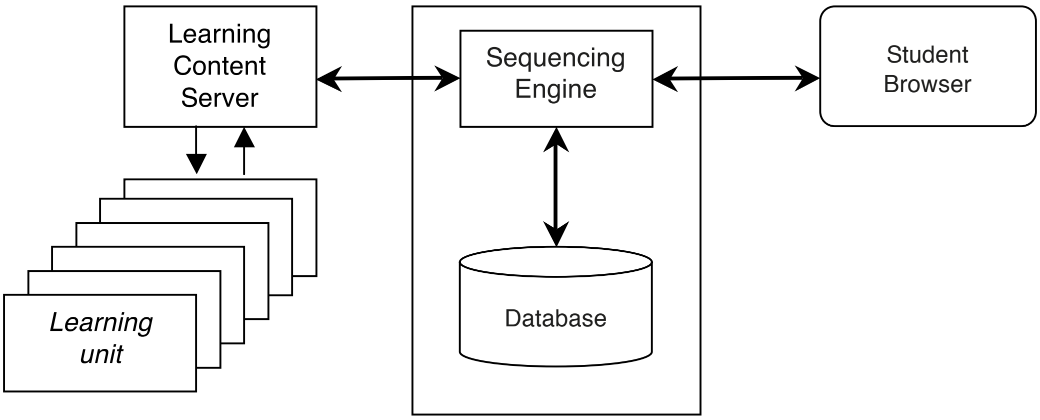

Figure 1. System architecture

The tutoring system

We have intend to develop an adaptive web-based tutoring system. The children are able to interact with the system using only a web browser. The system presents them some exercises, and adapts the sequencing of these exercises to their needs.

In this section, the technical architecture of the system is presented, while the techniques used to adapt the sequencing are presented in Sections **Sequencing graphs** and **Plain graph**. The architecture of the system is shown in figure 1.

Each part is described below.
*The database***.** The database contains all the information relevant to the system.
*Client***.** The client at the user side needs web basic navigation capabilities only.

*Content server***.** The content server contains all the information to be delivered by the system to the child, whether it is plain web pages or any other thing that is readable to a plain web browser.

*Sequencing server***.** The main part of the tutoring system. It retrieves the *learning units* from the Content server(s) and delivers them to the child.

Sequencing graphs

Sequencing graphs, presented here, are based on the ideas of [45] with some differences. They specify how to sequence learning activities in our system. They are powerful enough to allow arbitrary sequencing in a simple and intuitive manner, yet they can cope with big amounts of activities without becoming unmanageable due to their inherent hierarchy. This hierarchy allows to store small amounts of connected activities (a plain graph) in nodes that are part of a higher level organization (another plain graph, but with graphs inside) and so on.

Plain graph

A plain graph is defined as follows: A plain transition graph G is a tuple (V, E) where V a set of nodes each of them is a learning unit and E is a set of directed edges connecting nodes in V.

An *environment* is a set of pairs variable-value, where information about the child and its relation to the graph can be stored. Attribute values are divided into two types: strings and integers. Changes in the environment are made after each unit is delivered (any output data is stored in it) and, more importantly, by the *actions*.

An *action* determines a change in the environment. This can be the addition of a new pair to the environment, the change of an existing one or the deletion of it.

A *prerequisite* or *condition c* specifies a Boolean expression, either a simple one or a logic composition of simpler ones. Operators allowed for integer comparison are =, <, >, ≤, ≥. Strings can only be checked for equality. The allowed Boolean connectives are: !, &, | for negation, conjunction and disjunction respectively.

An edge α ϵ E is a tuple (*v1, v2, c, A*) where *v1, v2* ϵ V. When condition evaluates to true, the corresponding transition is suitable to be taken. Should the edge be followed, the corresponding set of actions would be executed, modifying the environment.

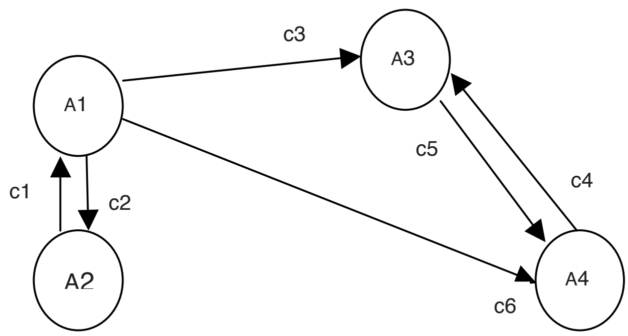

Figure 2. Plain graph example

Many out coming edges are suitable to be taken; one of them is selected in a nondeterministic way. Figure 2 shows an example of a plain graph. Nodes A_i are learning units: theory, conditions, examples, exercises, solutions, explanations, etc.

At all times the system has a current state S^c which represents the last activity or learning unit delivered to the user. When the unit has been finished, the set of available next units is selected according to the conditions that evaluate to true in the out coming edges. The child then has the opportunity of selecting which unit he wants to go to.

Hierarchy. Sequencing graphs.

Although these graphs provide a powerful and flexible mechanism to express sequencing of learning units, they may become too complex for a large number of units. In this situation defining a large transition structure can become infeasible.

A sequencing graph is thus defined recursively as follows:
A *sequencing graph* SG = (V, E, V_i, V_0) is a tuple where elements in V are either learning units or sequencing graphs, E is a set of edges, $Vi \cap V$ is its set of input nodes and $V_0 \cap V$ is its set of output nodes.

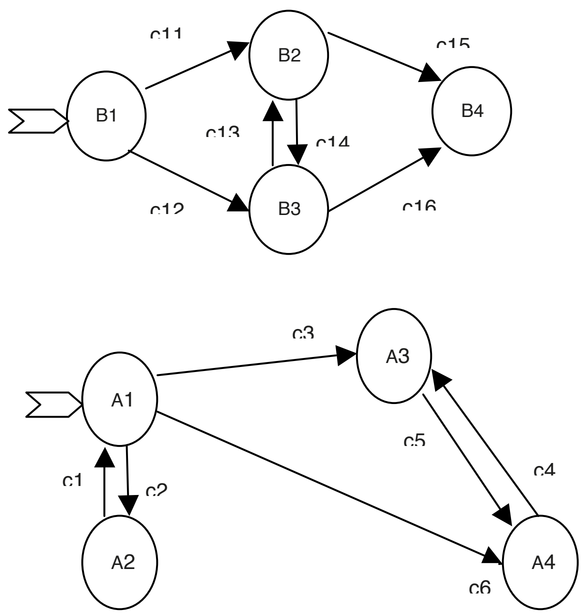

Figure 3. Sequential graph hierarchy example

With this new definition, a sequencing graph is a set of learning units and subgraphs connected among them by a set of edges. The input nodes are the possible entry points from a higher level of hierarchy. The output node are those with arcs directed to the upper level of hierarchy. The number of input and output nodes is not bounded in the general case. When there is one and only one input and one and only one output node in each plain subgraph, we call that a *strict sequencing graph*.

The possible sequencings defined by a sequencing graph are very intuitive to see. Nevertheless, in [45] the traversing algorithm is formally expressed. As we have not made any change to that, we do not repeat it here for the sake of space.
An example of a sequencing graph is given in Figure 3, with two levels of hierarchy which nodes are labeled with letters A and B. Input nodes at each level are marked with a white incoming arrow, and output nodes are marked with a cross, representing the edge going “upwards”.

Reinforcing the best paths

Not all possible sequencings are well suited for learning. That’s why some of them are permitted and some of them are not. (i.e. it makes no sense to deliver a child the last assessment if he has not been presented the former theory units.) That is why some arcs exist between units and some do not. Moreover, the arcs have prerequisites to match before the child is allowed to travel from one unit to the next one, and this is how the sequencing is adapted to different children with different capabilities or needs (this is sometimes called link hidding [38]).

But this approach has two weaknesses. First, it relies on some human designer/teacher to design the graphs. While this gives the opportunity of reusing the expertise of a teacher, it makes it harder to maintain the system in the long term. The use of hierarchy mitigates the problem, as some lower-hierarchy graphs can be remade from scratch without affecting the general graph, but it still requires a lot of work to add new learning units to a existing graph.

Additionally, child groups change over time. Different generations have, as a group, different capabilities and needs. It would be desirable that graphs offered the possibility of adapting themselves to different populations of children, and not only adapting the sequencing of learning units to every child according with some rules. As it is pointed out in [52], the set of paths designed at first would not be adequate after all.

We have tried to overcome these problems with the addition of some stirmergic capabilities to our system. Thus, successful paths are reinforced in order to guide children through the optimum path for their learning. The mechanism is similar to the one used by ants for reinforcing the paths leading to food sources through the use of pheromones.

When a unit is delivered to the child, his success or failure is recorded. If there was a success, information is stored about the actual activity and the former one. Thus, not only has every arc prerequisites to be accomplished by the child, but also information about how many children were successful when traversing it.

This information is presented to the child every time he finishes one unit. All the available units are presented to him. Each of them has information attached, about how many children have gone to each of them starting from the same unit as the child hast just finished. That way, the child has the ’ratio of success’ for each unit, according to the data collected from his peers. The result brings some similarities to a collaborative filtering system, but applied to adaptive sequencing.

A child that knows that he is above average compared with his classmates can select to do a unit that has a lower ratio of success but represents a higher challenge. A not-above-average child will be able to select those units in which many of his classmates were successful. This rep resent an additional degree of adaptation. Its big advantage is that it is achieved in a distributed and automatic fashion, and gives a sensation of freedom and self-control to the children about its own learning, which is very positive.

As many collaborative filtering systems, the platform proposed is suitable of being affected by the *cold start*[1] problem. This means that, at first, there is no information on the arcs, so no information can be presented to the children. This is a big problem in recommendation systems, as they need data to be useful to customers, and they need customers to use them to collect the data, but the users will not use a system that is not (yet) useful to them, producing a deadlock.

This will not be a blocking problem in our system because of two reasons. First, the learning units delivered to the children are useful on their own. They will attract the children even if there is no other feature in the system, either of adaptability or filtering or anything.

Moreover, the system inherent adaptability capabilities, through the prerequisites, that should prove to have some beneficial effect on the children' learning even before there is any meaningful data about their paths.

This process of "child clustering" can be directed by the child themselves. Existing systems shows only how children have performed to far as a group. If the names of children is shown (e.g. "A, B and F suceeded here"), next children have the opportunity of following those children (i.e. classmates) with whom they feel more identified. This approach presents some social concerns (e.g. privacy), so it is inhibited in the system.

The children will be able to interact with the tutor for some months. As time progresses, arcs will be reinforced and the children will have more information available to them about the following learning units. We plan to see the influence of different factors as: presence of the reinforcement information, importance of the reinforcement information (i.e. cold start very notorious or not), influence of first or more capable child on the results of their classmates, appearance of local optima. Based on the collected data, an improved version of the platform will be developed.

Another issue to be studied in future versions of the system is how far the reinforcement to be placed has. We will reinforce only the last arc traversed by the child. No studies have been conducted to find which grade of *pheromone spreading* is adequate for an e-learning application, as far as we know.

An intelligent tutoring system with some swarm intelligence capabilities based solely on hierarchical graph, which led to good results in experiments with real children. Adaptation to the children, necessary for a more effective learning experience will be achieved through two means: first, the use of sequencing graphs allows for

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1 *Cold start* is a potential problem in computer-based information systems which involve a degree of automated data modelling. Specifically, it concerns the issue that the system cannot draw any inferences for users or items about which it has not yet gathered sufficient information.

sequencing adaptation, while the analysis of the successful paths traversed by the children allow the modification of the graph to better confront the needs of a population of children.

Additionally, it gives more information to them about the following activities to be performed. After finishing each learning unit, the children are presented a screen with next available units (depending on the accomplishment of some prerequisites on the graph), with information about how well their classmates performed in those units when they departed from the same unit. In this way, optimal paths for the learning of the children can be found.

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 child 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.

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 *learning units* and add believable pedagogical agents in hopes of increasing child motivation to interact with and learn from the *learning units* in addition to providing implicit teaching and an immersive environment. Adaptation allows tracking learner performance through employing a child model and providing challenging activities in the learner'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 child. In this paper, we describe an augmented reality serious game that provides personalized learning experiences to the learners and can be used on mobile devices.

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 learner's engagement and contribute to several elements that have been shown to increase child 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 child learning.

Creating a believable pedagogical agent should further enhance the child 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 child 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 children which showed that children' 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 behaviours [22]. In addition, a believable agent must be believable within the context of the activities presented.

The Learning Unit

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 Learning Unit involves creating an augmented reality serious game that incorporates a believable agent in order to increase child engagement in the activities in a meaningful way that promotes learning and the development of problem solving skills. The child 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. After the initial introduction to the agents and initial assessment of the child level with some pre-assessment activities, the child 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 sections describe the Learning Unit architecture and the rationale behind the current design.

Overall architecture

The proposed Learning Unit 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. 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 Figure 4.

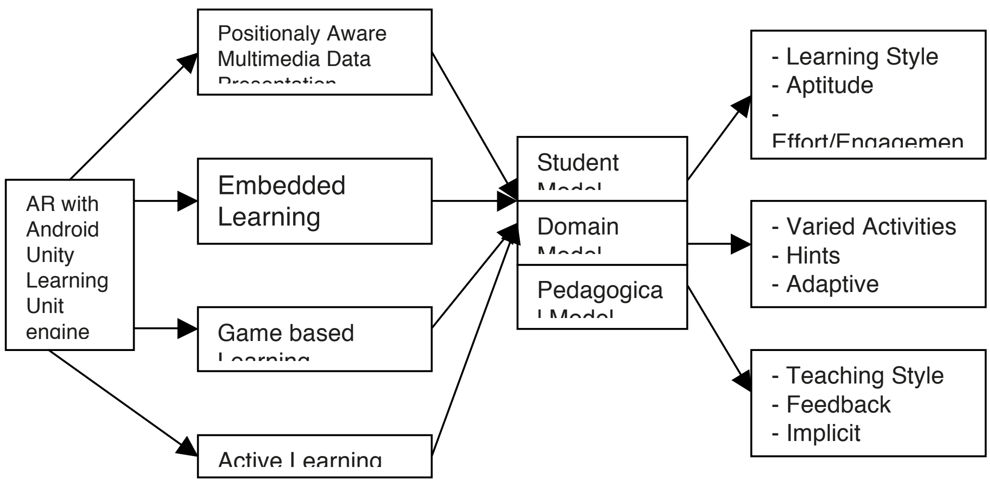

Figure 4. The architecture of Learning Unit

The architecture utilizes multimedia presentation, active learning, game based learning and pedagogical techniques in order to maximize child 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.

Embedded learning gives context to abstract skills. We plan to incorporate intelligent tutoring modules into the Learning Unit in order to add independence to child 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].

The architecture involves the interaction between a child model, a domain model and a pedagogical model. The child model will hold child information about the child'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 child 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 child model.

Design of the system

The Learning Unit 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 Learning Unit world are sewed into the background story. The game employs a child 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 child to acquire simple units (skills) that form the basis for developing other complex skills, which has proven to be a successful teaching strategy [27].

Conclusion

Problem solving is an important cognitive skill that highly impinges on other cognitive skills, such as computational thinking. Studies have shown that high school children 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 children about those meta cognitive 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 child 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, geo tagging, 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.

Each Learning Unit is 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]; the Learning Unit allows the learner to bring in their favourite 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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