An Intelligent Fractions Learning System: Conceptual Design

Teemu H. Laine
University of Eastern Finland
P.O.Box 111, 80101 Joensuu, Finland
thlaine at cs.joensuu.fi

Andrew Cyrus Smith
CSIR Meraka Institute,
PO Box 395, Pretoria, 0001, South Africa
acsmith at csir.co.za

Thato Foko
CSIR Meraka Institute,
PO Box 395, Pretoria, 0001, South Africa
tfoko at csir.co.za

Abstract

UFractions is a ubiquitous learning environment which combines mobile technology, tangible fraction blocks and a story-based game into a mathematical learning experience. In this paper we present a novel concept for monitoring a user's interaction with UFractions. In particular, monitoring is done by embedding intelligence into the fraction blocks. The approach presented allows for real-time monitoring and feedback to the user. Data captured with the proposed technology can be analysed at a later stage and provide valuable information regarding the child's thinking process. Group interaction is also increased because of the proposed large block sizes.

1. Introduction

South Africa is a context where approximately half of the population live in rural areas [1]. At the same time, access to mobile phones especially in case of adolescents is high [2]. Due to this reason mobile-phone based learning applications can be seen as potential ground for bringing education for all, regardless of cultural, societal or geographical background. Researchers at University of Joensuu have previously developed UFractions (Ubiquitous Fractions), a mobile phone based ubiquitous learning environment, specifically for assisting children in South Africa to learn about fractions. UFractions is essentially a game that features a story of leopards that interact with the learner through the phone. Leopards pose questions and children make use of colourful fraction blocks, similar to Cuisenaire rods [3], to find the correct answers. These blocks come in different colours and each colour has a specific length. The answers are entered using a mobile phone keypad.

The objective of the current research is to extend the existing system to incorporate 'intelligent' fraction blocks. We hypothesise that the system will be more responsive, to learner's actions, when 'intelligent' fraction blocks are used. In the proposed version of UFractions, the child would no longer enter answers using the phone's keypad, but the blocks would automatically report correct and incorrect attempts to the server. The server, in turn, would provide feedback to the child through the phone.

Our main motivator for conducting this research is to make the game more responsive by introducing intelligence to the physical manipulatives. Intelligent fraction blocks can provide continuous block placement data to the server, providing information on the attempts made by the child in reaching a solution. The block positions, as well as their relation to adjacent blocks, can be determined. Using this data, the custom written teaching software may automatically provide hints and scaffolding aid to the child on how to solve the given problem. In addition, the system can log the attempts made and provide valuable research information on how a child attempts to solve problems. This includes studying the different strategies of block manipulation.

In this paper we first describe background of the research. Then we present the design of the intelligent blocks, the surface, and what kind of changes the integration process requires in the existing UFractions server. Finally, we conclude the findings and discuss implications of the proposed concept.

2. Background

In order to give the reader an idea of what the proposed concept is based on, this section provides the necessary background information from perspectives of pedagogy, existing UFractions system, and previous work on intelligent tangibles.

2.1. Pervasive and ubiquitous learning

Mobile learning, or m-learning, is a form of technology-enhanced learning where the learner traverses across a physical context or contexts carrying a personal mobile device which provides learning material and activities [4]. The key idea of m-learning is to enable anywhere-any time learning experiences that can be shared through ubiquitous network connectivity. Recently, special branches of m-learning have also emerged, namely pervasive learning [5] and ubiquitous learning [6]. Figure 1 illustrates the distinction among the basic four learning types in the domains of embeddedness and mobility.

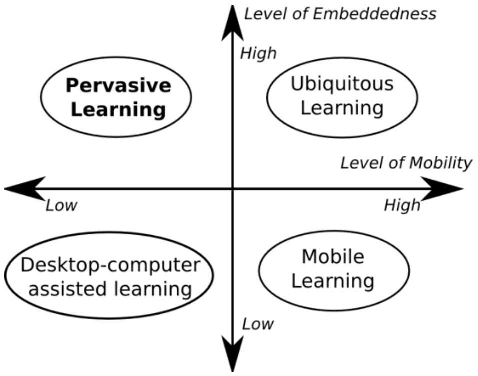

Figure 1. Types of learning in terms of embeddedness and mobility [22].

Embedded means the extent to which the physical environment is embedded with intelligent technology such as sensors and smart tags, whereas mobility refers to the spatial mobility of the learner. The terms pervasive and ubiquitous are often used inconsistently and interchangeably in computing, but there exists a clear distinction between the two in terms of mobility; while ubiquitous learning refers to everywhere, location-agnostic type of learning, pervasive learning concentrates on a limited geographical area but it also concerns the time, activities and actors within the context. In other words, a pervasive learning environment is typically very context-specific whereas a ubiquitous learning environment works well across contexts. Despite the differences at the conceptual level, the same technologies (e.g. mobile devices, sensors, smart tags) can be applied to both ubiquitous and pervasive learning.

2.2 UFractions

Using mobile devices for teaching mathematics is not a new idea (e.g. [7-9]) but there are not many solutions that connect the mobile technology to the surrounding objects in order to utilise them in the learning process. UFractions is a story-based mathematical game which combines mobile technology with tangible mathematical manipulatives. These mathematical manipulatives are in the form of fraction sticks. The storyline used in UFractions is based on mother- and cub leopards. The player's task is to help the leopards survive in the wilderness by solving fraction problems. The leopards pose problems to be solved to the player. These problems are presented on the phone and the player uses the fraction sticks to calculate the answer to the problem. The answer can be either in the form of a multiple choice selection, or a numerical input. Hints are given when the player is not making progress. Three levels of difficulty cater for a variety of players.

UFractions was contextualised to a South African school environment by using characters, colours and skill levels appropriate to the context and to the end users. Figure 2 presents a set of screen captures during the game play. In these for screens Mother Leopard asks the learner to solve a simple introductory challenge which involves the use of rods with two colours, each colour having a specific length. Figure 3 are photographs taken during a test session. Testing was organised in five South African schools during March 2009. During this time a total of 105 grade 8 pupils played the game. Part 1 of the evaluation is available in [5].

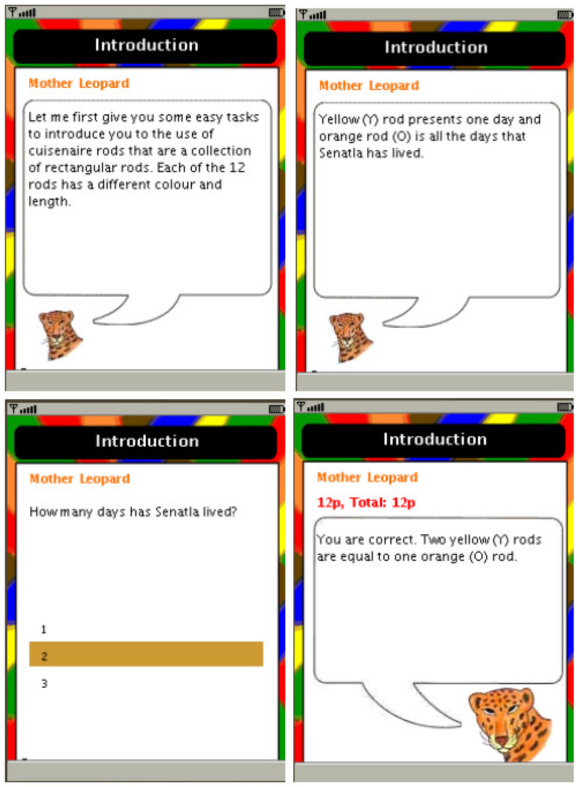

Figure 2. UFractions user interface.

Figure 3. UFractions test sessions.

The game system is the same that used in the LieksaMyst pervasive learning environment [11]. It is based on a client-server architecture in which the server pushes all data to the client and the player's actions are forwarded to the server to be analysed and reacted upon. Game logic, rules, content, and the player's status, are stored on the server. This approach is particularly useful when dealing with error-prone mobile technology. Should a phone become non-responsive or fail to function properly, the phone can be rebooted and the game will commence from where it was interrupted. Furthermore, if changes are made to the code or to the content, the players need not re-install the client software.

UFractions, as a tool, supports ubiquitous learning better than pervasive learning. This is because the context does not remain fixed. On the other hand, this context-agnostic characteristic also assures that UFractions can be potentially used anywhere as long as a mobile device and a set of fraction sticks are present.

2.3 Prior work on intelligent tangibles

Prior research on low cost embedded interaction technologies have shown that learning systems designed specifically for developing regions are indeed possible [12]. An example of such a system is RockBlocks [13]. RockBlocks is crafted from natural stone and mounted on a wooden square with embedded magnets (Figure 4). When these rocks are placed onto a sensing surface, the orientation of the rock is sensed and transmitted to dedicated electronic circuitry for interpretation.

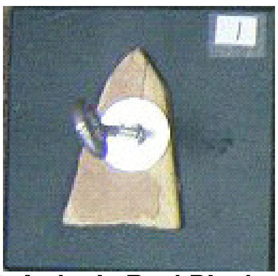

Figure 4. A single RockBlock element.

Intelligent tangible blocks have been used successfully in Tanzania where Lund and Vesisenaho [14] worked with I-BLOCKS intelligent blocks together with secondary school pupils. The idea of I-BLOCKS is to allow 'programming by buiding' which means that the learners can use the blocks to construct sequences of actions without any skills of traditional programming languages. According to Lund and Vesisenaho, I-BLOCKS are useful for three purposes: (1) Mathematical training, (2) emotion construction), and (3) language grammar training. We will discuss the differences between I-BLOCKS and UFractions with intelligent blocks in the conclusions section.

2.4 Pedagogical design

The study is grounded on the social constructivism paradigm which is closely associated with many contemporary theories, most notably the developmental theories of Vygotsky [15], and Bruner and Bandura's social cognitive theory [16]. The paradigm, as proposed by Vygotsky, goes beyond the Piaget's constructivism theory of constructivism as it incorporates developing a fully cultural psychology, stressing "the primary role of communication and social life in meaning formation and cognition" [17]. Vygotsky's main relevance to constructivism derives from his theories about language, thought, and their mediation by society. Many proponents of social constructivism elevate knowledge creation from the individual to a group of individuals [18]. There is the socio-cultural conception of learning as a collective, participatory process of active knowledge construction, emphasizing context, interaction, and 'situatedness' [19] . Those who believe in this paradigm agree that learning is a social construct which is mediated by language via social discourse. Therefore, the introduction of a social constructivism paradigm opens spaces for new experiences and voices, particularly those which are not considered important in the traditional learning environments, i.e. those of learners.

Criticism levelled against social constructivism is the type of learning it supports. Taylor argue that while it may be true that social negotiation is a useful approach to achieving consensual understanding of ill-structured subject matter, even in the 'softest' subjects there is often a body of undisputed knowledge.

Social constructivism therefore supports pervasive learning environments. It is through the UFractions that 105 grade 8 learners from across South Africa participated in groups of two and three to find solutions to the challenges provided by the UFractions. These learners analysed and discussed questions together and agreed on a solution hence learning became a social process. Social constructivism is a very effective tool for enhancing learner performance where learners work in groups and use social dialogue to solve the problems presented during game-play [20].

3. System design

The fraction blocks and sensing surface are constructed using low-cost materials, appropriate for developing regions. For the first prototype brightly stained/painted wood will be used.

3.1. Blocks

The system consists of a number of learning blocks, modelled after standard fraction blocks, but with much larger dimensions. In such a system magnets are embedded inside the blocks. Larger dimensions are recommended for three reasons:

- to support the embedding of electronic circuitry into the blocks,
- to provide an accessible learning system for children with fine motor skills problems, and
- to allow a larger group of children to work together on the given problems while having other children as active observers (Figure 5).

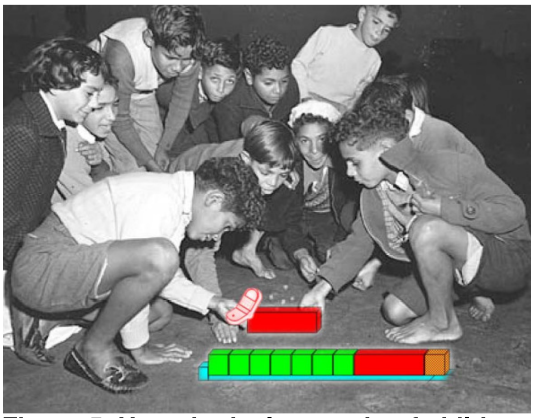

Figure 5. Hypothetical scenario of children playing with intelligent UFractions.

3.2. Sensing surface

In using the system, blocks are placed on a sensing surface. The sensing surface consists of two tracks, A and B (Figure 6). Track A is used for capturing the child's final answer to the problem. Track B is used by the child while experimenting with the solution to the problem posed.

Sensors embedded in this surface determine the time the blocks are placed or removed. This data is sent to the server for immediate analysis and capture in a database for further analysis later.

End stops on the left of each track (Figure 6) are integral to the tracks. The end stops serve to prevent the fraction blocks from falling off on the left, especially when the LockBlock is pushed against the fraction blocks on Track A.

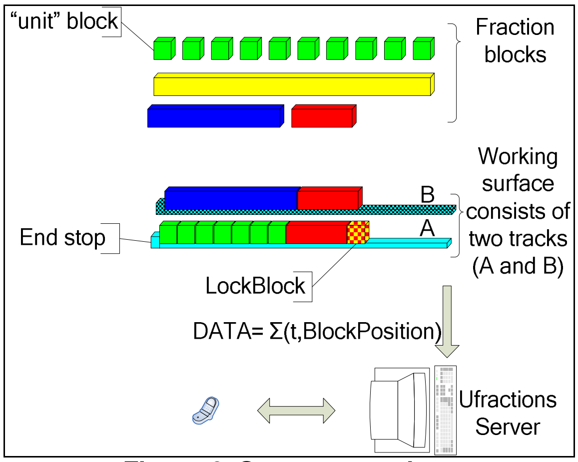

Figure 6. System overview.

3.3 User interaction

The server sends / receives interaction data to / from the application running on the mobile phone. This data may include one or more of the following parameters:

- a block's addition and/or new position,
- a block's removal from the surface (a child is holding the block),
- the position and direction of the block in relation to its adjacent blocks,
- the connection/disconnection of the block to/from an adjacent block,
- the user indicates her final answer by placing the LockBlock at the end of the fraction sequence (on the right in Figure 6). This serves to "lock" the final answer into the system, very much as is used in quiz games on TV where a switch is depressed.
- the fraction sequence starts at the extreme left of tracks A and B.

By using these values we can create a model of the child's interaction with the blocks and thereby determine, for example, if the child is continuously trying to solve the question using an incorrect approach. Successful solutions will be detected and immediately reported the child.

Immediate feedback is a crucial aspect of the system as the blocks are not able to give feedback. A user might easily be confused if the feedback arrives after a delay or does not arrive at all. Once the server has received interaction data from the surface, it must analyse the data and decide the next course of action. The system prototype will provide rudimentary feedback for failed attempts, successful attempts, and continuously failed attempts. The feedback will be sent to the child using the phone as a communication device. Here the leopard avatars act as the messengers. Sound effects will be used to draw the child's attention to the feedback on the mobile phone.

3.4 Integration to the UFractions server

A custom message protocol must still be defined for establishing a communication link between the game surface and the UFractions server. An additional module will be programmed on the UFractions server. This module will communicate with the game surface by a defined API over a wireless network. Using this message channel, the server will receive interaction data from the game surface. Feedback to the phone will be accomplished using the existing server architecture where the server pushes messages to the clients in XML format [21].

The UFractions server will also implement a database. This will be used as an archive of the captured interaction data and later used for analysis- and other research purposes. Stored data can be used, for example, to create user interaction models on which more sophisticated game features can be based in future systems.

4. Conclusions

The current system concept is an example of the integration of three ubiquitous/pervasive technologies: a ubiquitous learning environment for mathematics, intelligent tangible blocks, and a sensing board. Only once the system has been implemented and tests with children conducted, will it become clear how feasible this concept is. The authors hope that this technology will have a positive influence on the design of other systems that support m-learning. Moreover we hope to show that one can build a working prototype system with low-cost materials, hence assuring the suitability for contexts with low financial resources.

In the background section we presented shortly the I-BLOCKS, an existing solution of programmable tangibles that can be used to learn mathematics, for example. The main differences between I-BLOCKS and U-Fractions with intelligent blocks are the different focus area, the use of mobile device and story-based game, and finally the use of cheap material in case of UFractions intelligent blocks.

Our ultimate goal with UFractions is to develop it to be fully context-aware so that for example when the learner goes to a local supermarket, the system can automatically detect the context and give related tasks to the learner. These context-sensitive tasks can also be referred to as everyday mathematics or contextual mathematics as they relate to everyday activities. To reach this goal, much work must be done to fully context-awareness and create meaningful connections to the world surrounding the learner.

5. Acknowledgements

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