

An Intelligent Fractions Learning System: Implementation

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Abstract: A combination of modern technology and hand-crafted items is used as a learning tool for children. Instructions from a server are relayed via a cellular phone network to the user. The user places hand-crafted objects on a transparent surface and their positions are captured with a motion camera. Captured data is immediately available to a teacher monitoring the child's activities and also stored for later analyses with the aim of improving the learning system. Centralised user monitoring frees valuable human resources. Limited field-of-view and optical alignment difficulties are some of the problems discussed.

Keywords: Input surface, manipulatives, mobile phone, fractions, developing region, Montessori-inspired manipulatives.

1. Introduction

A set of fraction blocks is a tool to learn about fractions, often used in schools. With large classes often in excess of 35 children, it is a burden on the teacher to give appropriate attention to each learner. The system described in this paper combines tangible learning objects with modern technology to provide a possible solution to this problem.

Fractions are an integral part of the South African school curriculum [1]. For the educator who follows a constructivist approach to teaching, tools that allow the learners to actively engage with physical objects is a priority. It has been reported in the literature that some young children prefer using manipulatives instead of on-screen interfaces [2]. However, with the poor teacher-to-student ratio in developing regions it is hardly possible for the teacher to take note of the children's use of the available tools. In developing regions, such as South Africa, this is even more relevant because of the limited access children have to computers. Making use of physical manipulatives as a teaching tool has benefits such as providing sensory engagement (weight, texture and shape), accessibility (objects are large and do not require fine motor skills), and group learning (multiple persons can interact with the manipulatives simultaneously, encouraging group discussion) [2].

The system described in this paper allows for co-operative learning because of the shared input interface provided by the manipulatives on the input surface.

Even if access to computers was not a limiting problem in developing areas, there is still a compelling reason for using physical objects to discover mathematical concepts instead of only using on-screen interaction. This is because physical objects can be quickly reconfigured by using both hands [3] as opposed to combining fragile mouse-cursor alignment with click-and-drag operations.

UFractions is a story-based fraction learning game which combines mobile computing and physical manipulatives. The system is designed to eliminate the need for the users to interact directly with a desktop computer, but rather to use their mobile phones. Motivation for this can be found in the level to which the mobile phone usage and ownership has penetrated the lives of children in developing regions. For the African continent in 2009, almost 30% of the population either owns a mobile phone or have ready access to one [4], making mobile phones an attractive option for integrating technology with teaching.

Although the system does not completely eliminate the use of computers (they are still required to capture and analyse the children's interactions), the scalability of the system makes it attractive in applications where automatic data capture is required.

This paper is structured as follows. First, we describe the objectives of the system. Next we present our methodology and an overview of the system. This is followed with implementation details and related work done by others. The section on results gives some insight to the problems experienced. We then provide an opinion on the business benefits our system could have. Recommendations and guidelines for future research follows this. The conclusion again provides a broad overview of the system.

2. Objectives

UFractions supports the learning process when children are first exposed to fractions. Our aim with the current research project is to extend the existing UFractions learning system to incorporate automatic data capturing. "Intelligent UFractions" allows a teacher to remotely monitor the children's progress during their interaction with the system. A teacher can now keep track, from a single geographic position, of multiple groups as they perform their learning activity and intervene as necessary. The expected consequence of using Intelligent UFractions is thus the efficient use of scarce teaching resources.

3. Methodology

We adapted an existing platform in order to expedite the development process. The game was constructed using the Myst pervasive mobile learning platform [5]. Using contextualization, the game story-line and challenges were adapted for the target audience in South Africa. The story was created with the aid of South African cultural experts, and a suitable level of mathematical challenges was defined by consulting local secondary-school teachers. The design of the input mechanism was similar to the approach followed in a craft project, with the design evolving through experimenting and appropriating available materials [6]. For example, rubber erasers were cut using a craft knife and then coloured using highlighter pens [Figure 1]. Fiducials [7] were attached to the bottom of rubber eraser blocks and a plastic ruler [Figure 2].



Figure 1: Readily-Available Materials are Easily Transformed into manipulatives

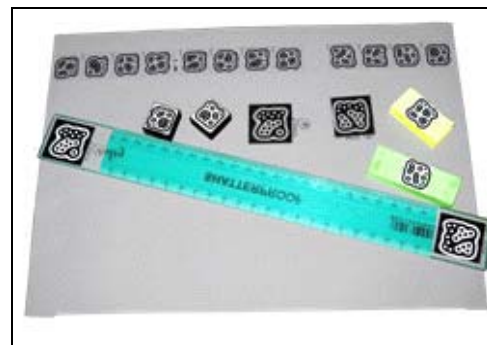


Figure 2: Fiducials Attached to Manipulatives.

4. System Overview

Our system consists of the Input Surface (with Blocks, LockBlocks, and track separator), Input Controller, UFractions Server, UFractions Client, and Web Server [Figure 3]. When in use, the UFractions Server receives a constant stream of Block identification numbers with their corresponding positions. Data is constantly streamed and stored for both immediate- and later analysis. Immediate analysis determines whether or not the user has entered the final answer. Later analysis is possible as an off-line process to gain insight into the user's approach in reaching the answer. The Server also generates a story and challenges, and communicates the challenges to the users via a TCP/IP phone using either WiFi or a 3G network.

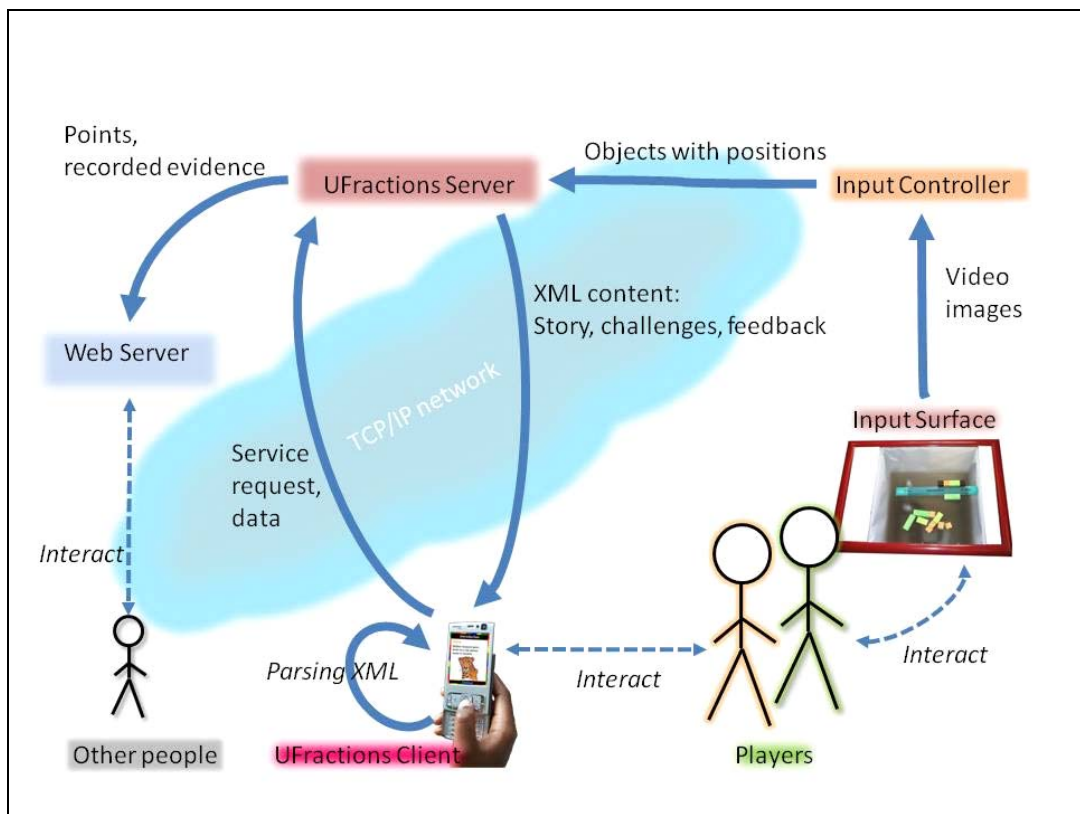


Figure 3: System Overview

5. Implementation

5.1 Logging

Prior research has shown that data logging should ideally be transparent to the user, without the user being distracted by it while executing tasks [8]. Our system automatically logs data every two seconds without any action required by the children. This allows for later interpretation of the users' actions.

Logged data are used in two ways: 1) when the LockBlocks are in place, data from the Input Surface is processed, feedback generated, and sent to the mobile phone. 2) when the LockBlocks are not present, interim data is processed and feedback given to the user.

5.2 The Input Surface

The input surface consists of a glass surface, a web camera and manipulatives. Manipulatives consist of a set of UnitBlocks, LockBlocks, and a Track Separator.

UnitBlocks

A combination of manipulative components are used to construct the answer. These are: 1•UnitBlocks, 2•UnitBlocks, 3•UnitBlocks, and LockBlocks. All blocks are integer multiples lengths of the UnitBlock and have different colours. Fiducials provide digital identification.

LockBlock

The design consists of two physical rows, labelled TrackA and TrackB. A user makes use of both tracks to determine the answer to the question and “locks” it in place by placing two LockBlocks on either end of the sequence [Figure 4].

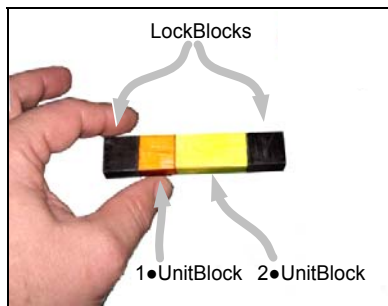


Figure 4: Proper positioning of the LockBlocks.

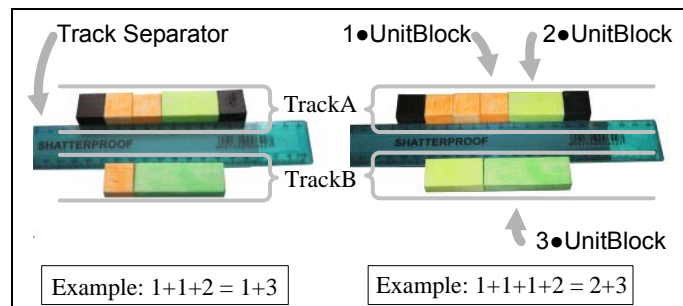


Figure 5: Two examples of fraction composition.

Track Separator

A plastic ruler, with unique fiducial identifiers attached to the bottom [Figure 2], defines the location of TrackA and TrackB [Figure 5]. A virtual line connects these identifiers.

5.3 – Software

The software consists of an Input Controller, UFractions Client, and UFractions Server [Figure 3].

Input Controller

The input controller software, written using Processing [9], interacts with reactIVision [10] to detect the fiducials, processes this data, and sends the UnitBlock sequences to the UFractions Client.

UFractions Client

Intelligent UFractions is based on the Myst pervasive mobile learning platform [11] which in turn is based on MUPE [12]. A client-server architecture “pushes” XML content to the client. The client is based on J2ME and renders a graphical user interface. Text, images, sound, and video are supported. The client can use the device’s camera, GPS receiver, and NFC reader. In addition, this client can be used to access any MUPE-based services over WLAN, GPRS or a 3G connection.

UFractions Server

The server can host a number of clients. In our tests we have had 15 connected simultaneously. The server receives data from the Controller over a TCP/IP network. This supports a geographically distributed system.

Communication between the Server and the Controller is via a custom protocol over the TCP/IP network. The protocol supports any number of tracks, each of which can have a varying number of Blocks. Received data is parsed and separated according to track. The bundle of track data is then categorised according to the presence of LockBlocks. If two LockBlocks are in place on TrackA, an answer is assumed. If no LockBlocks are in position then data is processed as interim data, allowing the server to initiate an intervention message to assist the player.

All game content is stored in XML format on the server, which sends data to Clients upon request.

6. Related Work

Here we briefly report on related work, specifically on input mechanisms and systems that allow for collaborative work.

6.1 – Input mechanisms

Computational construction kits [13] sense the user's actions while manipulating physical geometric objects. These objects are augmented with sensors, creating a link between the physical- and digital worlds [14].

Closely related to our research is the multi-touch table. This is an input technology that has recently received significant attention; see [15] for an example. The table allows one or more users to interact with digital data by using finger gestures on a two-dimensional surface, eliminating the use of “traditional” computer accessories such as the keyboard or mouse.

6.2 Working Collaboratively

Sharable interfaces have previously been classified as “distributed systems” and “single display groupware”. Distributed systems provide simultaneous multiple interfaces to a single system, with a single user interacting through an interface. Single display groupware refers to a system with multiple simultaneous input mechanisms and a single display [16].

Prior research reports that children enjoy working in a collaborative space if they all have simultaneous opportunity to provide input to the task at hand [17]. Because our system provides the opportunity for multiple users to participate simultaneously, we anticipate that children will have an increased level of satisfaction when working in groups as opposed to working individually. Our system can be described as “single input, multi display groupware”.

6.3 UFractions

UFractions is an educational game to teach children about fractions, using a story that poses challenges to the children via a mobile phone application connected wirelessly to a remote server. Children calculate the answer with the aid of passive manipulatives and enter the result on the phone. In 2009, a mobile phone-supported UFractions system was tested in South Africa [18].

7. Results

A number of challenges were encountered during the design and implementation of this research project. The optical subsystem used for capturing the children's activities posed the most challenging. We next describe how these challenges were overcome.

7.1 *Fiducial Size and Camera Distance*

The camera's field-of-view and optical resolution required a trade-off between the size of the fiducials and the number of the fiducials that can be placed on the surface at any one time. With a 2 megapixel camera with a 70° field-of-view placed 300mm below the glass surface, a total of 12 fiducials can be detected when placed end-to-end and across the diagonal of the observable view. This makes provision for 10 off 1•UnitBlocks, plus two LockBlocks on the Input Surface at any time. Using this configuration, two rows of 12 fiducials each can be accommodated. In addition, two more fiducials can fit between the rows. These were used to define a virtual line.

7.2 *The Track Separating Line*

We had to align the tracks along the diagonal of the Input Surface due to the camera's limited field-of-view and resolution. Determining programmatically along which track a Block lay posed a problem. A solution we considered was to hard-code the position of the separating line and to carefully install the camera so that its physical orientation matches this virtual line. However, we implemented a more elegant solution as follows: when two unique fiducials are placed between the rows, a virtual line can be constructed that connects the fiducials. It was now a simple matter of attaching these fiducials to a straight object (track separator) to define the physical separation of the two tracks [Figures 2,5].

7.3 *Allocating Blocks to Tracks*

The Input Surface allows for an infinite arrangement of the dividing line's position and orientation; and as a consequence an infinite number of positions for TrackA and TrackB. In addition, the reactIVision software provides Block positions according to the camera's co-ordinate system and not according to the separating line's co-ordinates. The solution to this dilemma is described next.

The two fiducials which define the separating line have unique IDs, making it possible to determine which fiducial defines the beginning of the line. Assigning each Block to the appropriate track has now been reduced to a simple geometry problem.

7.4 *Lighting Conditions*

The automatic exposure adjustment the camera makes is a problem. When the ambient light reaching the camera sensor from the environment is high, the camera automatically compensates by darkening the image to keep the overall level within some factory pre-set limits. The result is that the contrast between the light and dark areas in the fiducial is too low for the reactIVision algorithm to decode the fiducial. We anticipate that this can be resolved through careful design of the Input Surface materials and lighting from below, and finding a mechanism to control the exposure of the camera.

7.5 *Dynamic Track Position*

Two dynamic tracks along a central physical straight edge is an unexpected benefit of using the optical track identification method. Now, the constraint of placing Blocks on physical

tracks [11] has been simplified to placing Blocks along the long edges of a ruler [Figure 5]. The ruler and Blocks can now be rotated during use according to the various users' preferred orientation, useful when many users collaborate using a single Input Surface.

8. Business Benefits

Digital manipulatives have the advantage over passive manipulatives in that they can provide real-time temporal information on the user's interaction. With the temporal information being captured, and not simply the end result as is currently the case in classrooms, the Intelligent UFractions system can be called an interaction system [19].

The benefits in using a system such as Intelligent UFractions lie in the centralised, and potentially remote, monitoring and data collection of children's actions while they are engaged in learning activities. Valuable and scarce human resources can be freed and applied elsewhere. In addition, a trained professional can analyse the captured data at leisure and gain an understanding of the children's thinking process plus their acquired training level. Improvements to the training material can be based on this knowledge.

9. Recommendations

A significant benefit of the Intelligent UFractions system is that real-time data collection and analysis become possible. The potential lies particularly in the processing and analysis of interim data collected between answers. In order to utilise this data efficiently, we recommend that a user model should be created by which the user's behaviour can be observed and acted upon. We have devised a set of scenarios in which interim data could be useful: 1) provide tutorial information for new players as they start to interact with the Blocks, 2) remind the player to use TrackA and two LockBlocks for answering if the player is trying to answer on TrackB or has the correct answer but no LockBlocks in place, 3) prompt the player after a period of inactivity, and 4) suggest which Blocks could be useful if the player is using Blocks that are irrelevant to the particular challenge.

10. Future Work

Evaluating the Intelligent UFractions system with children will highlight the strengths and weaknesses of using this approach to teaching fractions to children. One dimension of special interest is the size of the Blocks used. The size of the Blocks, as implemented in the current design, is not much different to current commercially available passive fraction blocks. It would be interesting to test Blocks that are twice- and four times larger to determine the children's preference. Tests will be conducted to determine the appropriate table size required to accommodate the larger Blocks.

As we experimented with the rubber pieces, we observed that it is possible to use almost any readily-available object by simply tagging it. We hope to involve the children during our trials to repurpose other materials they have easy access to. By simply adding a fiducial paper tag to the bottom, the object can serve as an input object to the system. In this way the input objects can be adapted by the children themselves; now a tool for children to explore their creativity in adopting objects for other purposes than what they were originally intended [20].

To complement this, the story and challenges of Intelligent UFractions can in the future be changed to create completely new kinds of educational games; games that combine intelligent objects with mobile-based storytelling. A future paper will elaborate on the user tests. In order to conclude the current implementation, additional effort will be required to programmatically determine the physical sequence in which the Blocks have been placed on the Input Surface.

11. Conclusion

In this paper we have explained the rationale for implementing a novel system for teaching children about fractions, a system that integrates physical manipulatives with digital technology. The integration of ubiquitous mobile phones with tangible blocks provides an attractive solution for learning systems in developing regions. Interaction design improvements became evident during the implementation of the system. It transpired during the implementation that low-cost objects (rubber erasers and a plastic ruler) can very effectively be repurposed instead of constructing manipulatives from raw materials.

In the original UFractions system the mobile phone's keypad was used to capture answers [5]. This was done by either choosing the answer from a list or by entering an integer. Answering UFractions challenges using the method described here is significantly different. To maximise the benefit offered by the Input Surface, we devised several alternative answering techniques: 1) ask the user to input a correct Block colour, 2) ask the user to input a small integer by using multiple Blocks of a given colour, 3) ask the user to input a fraction by using two Blocks of different lengths, 4) ask the user to input a mixed number by using TrackA for whole number and TrackB for the fraction part, and 5) label Blocks with numbers and prompt the user to input a number by using Blocks as digits. Some of the original UFractions challenges could not be converted to support these answering techniques because they require textual answers (multiple choices). We therefore decided to leave these challenges intact, allowing the user to enter answers using the phone's keypad.

The experimental system described here is a blend of modern technologies and hand-crafted objects. No specialised hardware is required to implement the system, and the software developed is available as open source. We anticipate that analysis of the data will be the biggest challenge to overcome if the system is to be used to its full potential.

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References

- [1] Newstead, K., and Murray, H. Young students' constructions of fractions. In Proceedings of the Twenty-second International Conference for the Psychology of Mathematics Education (1998), A. Olivier and K. Newstead, Eds., vol. 3, pp. 295-302.
- [2] Zuckerman, O., Arida, S., and Resnick, M. Extending tangible interfaces for education: digital montessori-inspired manipulatives. In CHI '05: Proceedings of the SIGCHI conference on Human factors in computing systems (New York, NY, USA, 2005), ACM Press, pp. 859–868.
- [3] Gorbet, M. G., Orth, M., and Ishii, H. Triangles: tangible interface for manipulation and exploration of digital information topography. In CHI '98: Proceedings of the SIGCHI conference on Human factors in computing systems (New York, NY, USA, 1998), ACM Press/Addison-Wesley Publishing Co., pp. 49–56.
- [4] Ford, M., and Botha, A. MObiled: mobile-led and leading via mobile. In Information Society Technologies (IST) Africa (2009).
- [5] Laine, T., Vinni, M., Islas Sedano, C., and Joy, M. On designing a pervasive mobile learning platform. *ALT-J Research in Learning Technology Journal* 18, 1 (2010), pp. 3–17.
- [6] Löwgren, J. *Hci Remixed*. MIT Pres, 2008, ch. 32 Interaction design considered as a craft, pp. 199 – 203.
- [7] Bencina, R., and Kaltenbrunner, M. The design and evolution of fiducials for the reactivation system. In Proceedings of the Third International Conference on Generative Systems in the Electronic Arts (2005).
- [8] Markopoulos, P., Read, J. C., Macfarlane, S., and Hoysiemi, J. *Evaluating Children's Interactive Products: Principles and Practices for Interaction Designers* (Interactive Technologies). Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 2008.

- [9] Reas, C., and Fry, B. *Processing: A Programming Handbook for Visual Designers and Artists*. The MIT Press, 2007.
- [10] Bencina, R., Kaltenbrunner, M., and Jorda, S. Improved topological fiducial tracking in the reactivation system. *Computer Vision and Pattern Recognition Workshop 0* (2005), p. 99.
- [11] Laine, T. H., Smith, A. C., and Foko, T. An intelligent fractions learning system: Conceptual design. In *Technology for Innovation and Education in Developing Countries* (2010).
- [12] Suomela, R., Räsänen, E., Koivisto, A., and Mattila, J. Open-source game development with the multi-user publishing environment (mupe) application platform. In *Proceedings of the ICEC 2004* (2004), Springer Berlin-Heidelberg, pp. 308-320.
- [13] Aish, R., Frankel, J., Frazer, J., and Patera, A. Computational construction kits for geometric modeling and design (panel abstract). *Proceedings of the 2001 symposium on Interactive 3D graphics* (2001), pp. 125–128.
- [14] Ishii, H., and Ullmer, B. Tangible bits: towards seamless interfaces between people, bits and atoms. In *CHI '97: Proceedings of the SIGCHI conference on Human factors in computing systems* (New York, NY, USA, 1997), ACM Press, pp. 234–241.
- [15] Wigdor, D., Leigh, D., Forlines, C., Shipman, S., Barnwell, J., Balakrishnan, R., and Shen, C. Under the table interaction. In *UIST '06: Proceedings of the 19th annual ACM symposium on User interface software and technology* (New York, NY, USA, 2006), ACM Press, pp. 259–268.
- [16] Rick, J., Rogers, Y., Haig, C., and Yuill, N. Learning by doing with shareable interfaces. *Children, Youth and Environments* 19, 1 (2009), pp. 321–342.
- [17] Inkpen, K. M., Ho-Ching, W.-L., Kuederle, O., Scott, S. D., and Shoemaker, G. B. D. This is fun! we're all best friends and we're all playing: supporting children's synchronous collaboration. In *CSCL '99: Proceedings of the 1999 conference on Computer support for collaborative learning* (1999), International Society of the Learning Sciences, p. 31.
- [18] Turtiainen, E., Blignaut, S., Els, C., Laine, T., and Sutinen, E. Story-based ufractions mobile game in south africa: Contextualization process and multidimensional playing experiences. In *Workshop on Story Telling and Educational Games* (2009).
- [19] Löwgren, J. How far beyond human-computer interaction is interaction design? *Digital Creativity* 13, 3 (2002), pp. 186–189.
- [20] Eisenberg, M., and Eisenberg, A. N. The design of children's technology. Morgan Kaufmann, 1999, ch. 11- Middle tech: blurring the division between high and low tech in education, pp. 243–273.