THE DEVELOPMENT OF A FRACTION TESTING AND TUTORING SYSTEM

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Abstract

One of the major areas in Computer Aided Learning (CAL) research has been the development of Intelligent Tutoring Systems (ITSs) for tutoring individual subjects through the application of cognitive tutor technology. In parallel to the use of computer aided learning (CAL), Computer Based Testing (CBT) has also been widely used for a variety of purposes. Studies have shown that fractions are one of the most difficult subjects to learn due to the complexity of the concepts and skills involved. Although there are various fraction tutoring systems available, most of them lack user interactivity and do not provide intuitive insight into the many concepts and skills associated with fractions. Furthermore, these systems are generally intended for longer-term learning use (e.g. weeks or even longer) and the effectiveness of using such systems is therefore usually difficult to assess. This paper presents the development of an interactive computerised Fraction Testing and Tutoring System (FTTS) delivered through the World Wide Web that incorporates learning capabilities for the purpose of both tutoring and testing fractions for school students aged 10-12. The system implements the cognitive learning model proposed by Derry in 1990. This system can perform fraction tutoring and at the same time undertake fraction testing. Results obtained from the use of this system can therefore be used to assess the effect of tutoring on students' performance.

Keywords

Computer Aided Learning, Computer Based Testing, Cognitive Learning Model, Intelligent Tutoring System, Fractions.

Introduction

With the rapid development of computers and related technologies, Computer Aided Learning (CAL) has become increasingly important in education at various levels (cf. Anderson et al., 1995; Goldberg et al., 1996; Hueyching,

1996; Wood et al. 2001). Compared with other learning techniques commonly in use, CAL has many advantages, including the provision of animation and interactivity, which can make it easier for learners to understand the courses under study more comprehensively, particularly to understand those concepts which are difficult to comprehend through other teaching techniques. CAL can also provide one-to-one assistance to learners, which can be extremely effective in improving their performance (e.g. Anderson et al., 1995; Koedinger et al., 1997; Koedinger, 1998).

One of the major areas in computer aided learning research has been the development of Intelligent Tutoring Systems for tutoring individual subjects (e.g. Nwana, 1993; Anderson et al., 1995; Koedinger, 1998; Alpert et al., 1999; Lee and Heyworth, 2000; Wood et al., 2001). Intelligent Tutoring Systems have been improved significantly since their beginning at the late 1970s and early 1980s due largely to the advances in education theories and computing technologies (e.g. Sleeman and Brown, 1982). Interactivity with the learners has been one of their most important characteristics. The primary objective of most ITSs has been the acquisition of cognitive skills by tutees through the tutoring sessions (cf. Anderson, 1983, 1993). Results from studies undertaken by Anderson et al. (1995) and Koedinger et al. (1997) show that the application of cognitive tutor technology could yield an increase of about one standard deviation effect on the students' performance, indicating the importance of ITSs in improving students' knowledge. In parallel to computer aided learning, computer based testing has also been widely used for a variety of purposes (cf. Archer et al., 2001; Fox and Schwartz, 2002; Thelwal, 2002; He and Tymms, 2004). Of the computerised testing procedures currently in use, Computer Adaptive Testing (CAT) has drawn particular attention in recent years (cf. Brown and Iwashita, 2002; Tonidande et al., 2002; Lilley and Barker, 2003; Lilley et al., 2004). Increasingly, computer based testing has been conducted through the Web. Some of the traditional standalone Intelligent Tutor Systems have been transferred onto the Internet (e.g. Alpert et al., 1999).

Substantial research activities have been applied to the study of CAL and computerised testing such as CATs. Existing CAL techniques generally represent a transformation of conventional learning techniques to computers (with added features such as animation and audio and video capabilities) and are suitable for longer-term learning activities, while computerised testing has been primarily used for ability assessment in specific areas. Little attention has however been given to the study of the use of computerised testing for both testing and tutoring - i.e. learning through assessment. In view of the features associated with computerised testing, it will be possible to incorporate learning techniques into computerised testing for the purpose of both testing and tutoring. The present study is intended to explore the potential for using computerised testing for learning the basic fraction concepts and skills.

Studies have shown that fractions are one of the most difficult subjects to learn due to the complexity of the concepts and skills involved (cf. Nwana, 1993). Although there have been various fraction tutoring systems available

(e.g. Nwana, 1993; Abdulla, 2000; Rand, 2003), most of them lack interactivity and do not provide insight into the many fraction concepts and skills. Furthermore, these systems are generally intended for longer-term learning use (e.g. weeks or even longer) and the effectiveness of using such systems is usually difficult to assess. The aim of the present study is to develop an interactive computerised Fraction Testing and Tutoring System that incorporates learning capabilities for the purpose of both tutoring and testing fractions for school students aged 10-12. The system implements the cognitive learning model proposed by Derry (1990). The system provides animated graphics to make it easier for students to understand some of the most important concepts of fractions and the basic skills used for solving fraction-related questions. This system has been developed as a Web-based application for wide access. The system can perform fraction tutoring and at the same time undertake fraction testing. Results obtained from the use of this system can be used to assess the effect of tutoring on students' performance.

Derry's Learning Model

In Derry's cognitive learning model, a student is assumed to be able to elaborate the connection between his/her prior knowledge and the new information presented and therefore to construct new knowledge. Figure 1 represents a graphic view of the model produced by Grow (1996).

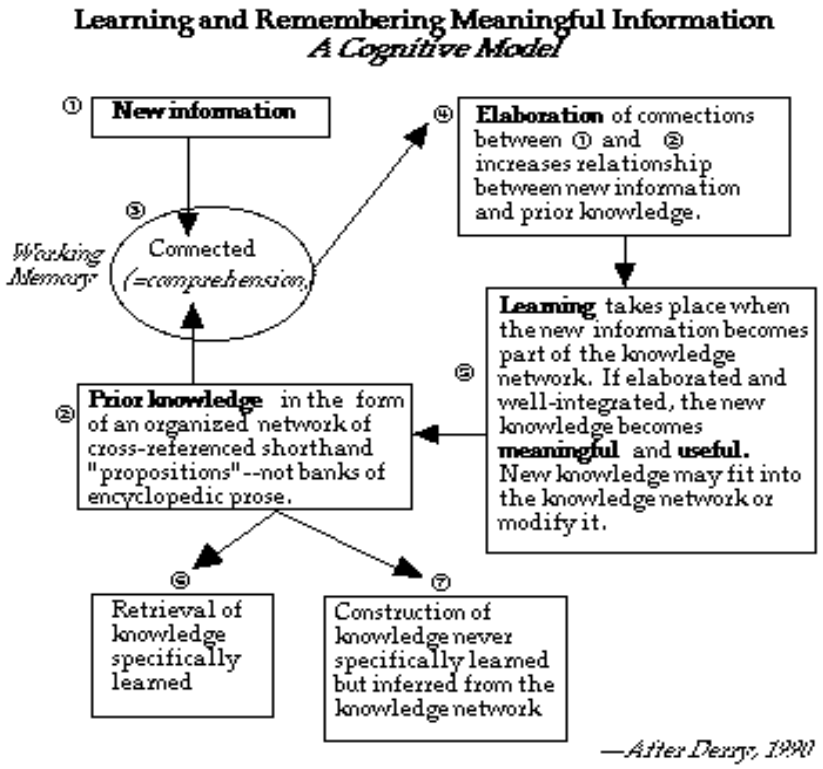

Figure 1. Derry's cognitive learning model (from Grow, 1996)

Referring to Figure 1, Grow (1996) suggested using three stages to examine the implication of the Derry model: comprehension (steps 1-3), learning (steps

4 and 5), and recall and reconstruction (steps 6 and 7). He suggested that comprehension of a question by a student depends on his/her prior knowledge and the strategies employed for analysing the question. However, comprehension does not necessarily lead to learning. In the learning stage, the student links the new information to his/her prior-knowledge through a variety of learning processes including elaboration of the question - searching for ways to solve the problem. Grow indicated that in the final stage of the learning process, recall and reconstruction of the new information acquired, takes place. The new information acquired is analysed and organized into his/her knowledge network to become existing knowledge for future use. In the present study, it is assumed the students can learn fraction concepts and skills during the process of using the FTTS through the various stages identified by the Derry model.

The Design and Implementation of the Fraction Testing and Tutoring System

The FTTS system has been developed as a Web application, and a client (the Web browser)-server (the service provider) architecture is deployed. The testing and tutoring system is located on a Web server and can be accessed via a Web browser. The FTTS contains four major components: the Testing and Tutoring Component (TTC) that provides the testing and tutoring module to the students; a Graphic User Interface (GUI) component that provides interface between the students and the TTC; a database, which is located on a database server, that is used to store responses from the students and other information such as item characteristics; and the Data Communication Component (DCC), which resides on the Web server as a Web service application and handles the data communication between the Web server and the database server. The client is the Web browser residing on the students' machines that loads the system onto the client machines. Figure 2 provides an illustration of the architecture of the FTTS system.

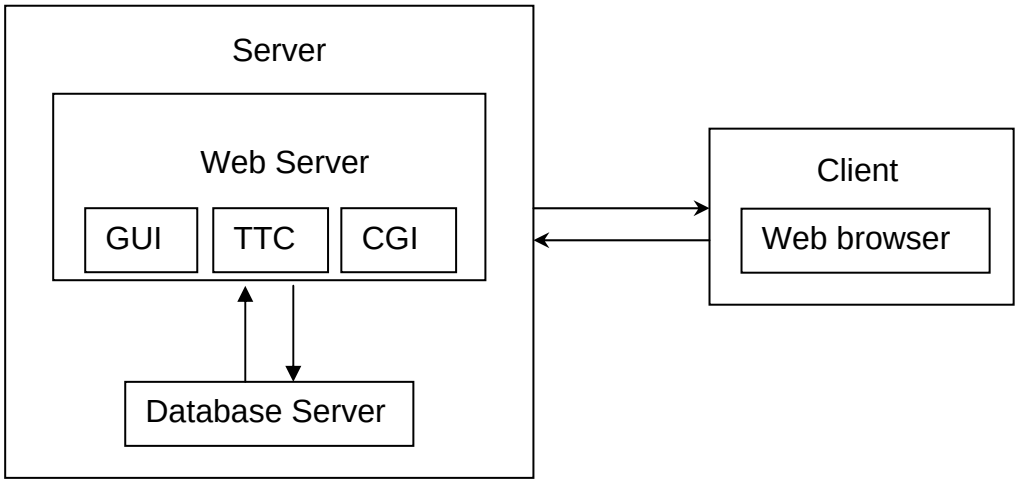

Figure 2. The client-server architecture of the FTTS system

One of the major objectives of the present study is to use animated graphics to illustrate some of the most complicated concepts of fractions and the most frequently used skills for answering fraction related questions. Macromedia Flash technology has been used to develop the TTC and the GUI components, as Flash is an established and widely used Web tool and most computers will already have the Flash player plug-in installed ready to play Flash movies. Flash also provides a significant number of animation tools. Furthermore, the XML object (Extended Mark-up Language, which has seen its increasing use as standard data transfer mechanisms between applications developed using different technologies) exported from Flash implements a client-server architecture, which makes it relatively easy to transfer data between the testing and tutoring GUI and the different components involved. The TTC and the GUI is combined as one Flash application. The GUI is used to display items to the students, show animated help content and generate response data as XML object to be exported to other components for processing. The TTC is an enclosed object and there is no data communication between it and the other components during the testing and tutoring session. Once the testing and tutoring session is completed, the response data will be exported as an XML object that will be sent to the Web server for further processing.

The Fraction Items

An item bank has been developed for use by the FTTS system. As the emphasis here is placed on testing the basic fraction concepts and skills, all questions used in the system are multiple-choice questions (MCQs) for easy implementation, and List 1 shows the question types that have been included in the item bank.

List 1: Question Types of the Fraction Item Bank

1. Multiplication of integers;
2. Representation of proportions using fractions;
3. Integer division and fractions;
4. Renaming fractions;
5. Addition of fractions with like denominators;
6. Addition of fractions with unlike denominators;
7. Subtraction of fractions with like denominators;
8. Subtraction of fractions with unlike denominators;
9. Converting percentages to fractions;
10. Converting fractions to percentages;
11. Converting decimals to fractions;
12. Converting fractions to decimals;
13. Converting decimals to mixed numbers;
14. Converting mixed numbers to decimals;
15. Comparing fractions;
16. Simplifying improper fractions to mixed numbers;

17. Expanding mixed numbers to improper fractions;
18. Addition of integers and mixed numbers;
19. Addition of mixed numbers with like denominators;
20. Addition of mixed numbers with unlike denominators;
21. Subtraction of fractions from integers;
22. Subtraction of mixed numbers with like denominators;
23. Subtraction of mixed numbers with unlike denominators;
24. Multiplication of fractions and integers;
25. Multiplication of mixed numbers and integers;
26. Division of fractions by integers;
27. Multiplication of fractions by fractions;
28. Multiplication of mixed numbers by mixed numbers;
29. Division of fractions by fractions;
30. Division of mixed numbers by mixed numbers.

Each item is an independent object – a Flash movie. Visually, the item is composed of 3 parts: the question itself in black, the four possible answers in blue, and the four selection buttons in brown. Figure 3 depicts an example of the item movies.

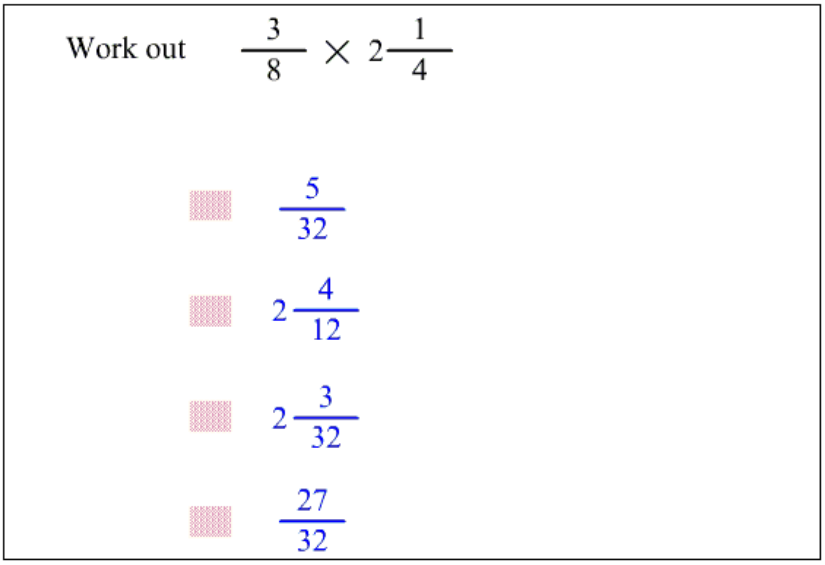

Figure 3. An example of the fraction items

The Help System

The TTC includes a help system, which is composed of 30 topics that correspond to the number of question types shown in List 1. That is, for each question type, there is a corresponding help topic. The help system comprises a collection of independent objects (Flash movies) representing individual topics and can be accessed as a whole or as individual help topics. It is the use of the help system during the testing and tutoring session that helps the

students learn fractions. A help topic movie generally contains 4 parts: a fraction expression showing an example, an embedded animation movie or movies for illustrating the processes involved in answering a fraction question, a 'Start/Stop' button for playing the animation movie or stopping it for close examination, links to other related help topics, a link to the terminologies used in fractions, and a 'Return' button to close the help topic movie. Figure 4 shows an example of a help topic – 'Addition of Fractions with Unlike Denominators' when it is initially displayed.

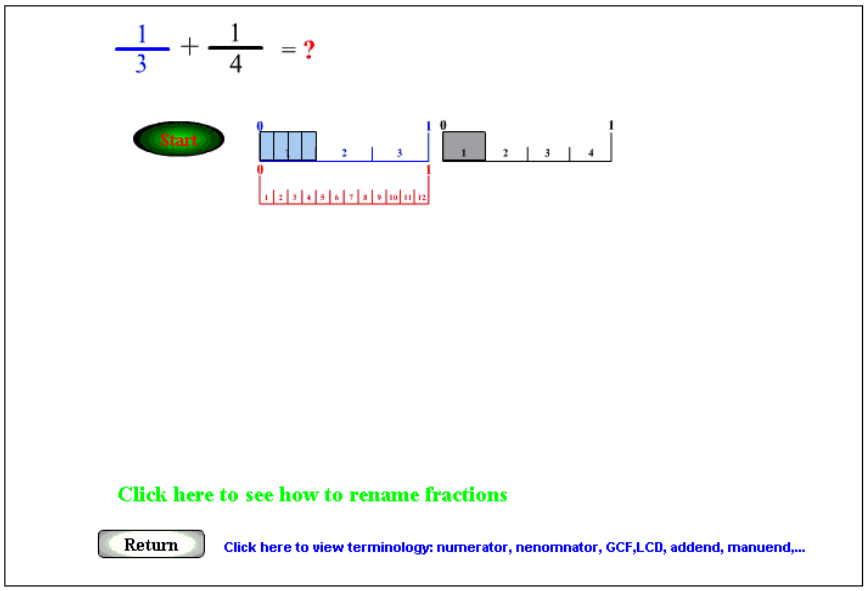

Figure 4. An example of the help movie clips when they are initially displayed

In this example, the addition of 1/3 and 1/4 is used to demonstrate the addition process involved. When the animation is being played, the 'Start' button changes to 'Stop'. The animation can then be stopped by pressing the 'Stop' button. When the animation is stopped, the 'Stop' button changes to 'Start' button. Clicking the 'Start' button again will continue to play the movie. This stopping and playing alternation allows the students to examine the addition process in detail and understand the concepts involved. Once the animation is completed, the 'Stop' button changes to a 'Reset' button to allow the animation to be replayed. Once the animation is completed, a text message is displayed explaining the logic leading to the result. Frequently used terminology is also explained or the user is directed to where this is explained.

The Testing and Tutoring Session

When the FTTS system is accessed, the user is asked to provide his/her personal details and presented with a text message providing explanation about the test he/she is going to take. There are 3 sections in the test, and the user will start with Section 1, then proceed to Section 2 and then to Section 3. All sections are timed.

- In Sections 1 and 3, the user can only select one answer which he/she thinks is the correct answer from the 4 possible answers for

each question. The user will not be able to get help in these two sections. Both sections contain the same questions, but the question orders are different.

- In Section 2, the user can get help for the current question he/she is working on if difficulty is encountered. The user will also be able to view the entire set of help topics at any time within the section time limit. This is where the learning process takes place.
- A summary of the test scores for each section is displayed at the end of the testing.

It is possible to assess the effects of the help obtained in Section 2 by comparing the scores for Sections 1 and 3.

Initial System Evaluation

Six students from a local school were asked to evaluate the technical aspect of the FTTS system. This was achieved by asking the students to complete a questionnaire when they were taking the test. Specifically, emphasis of the evaluation was placed on the following areas:

- The ease of use of the system
- The clarity of the instructions provided by the system
- The clarity of the questions contained in the system
- The usefulness of the animations provided by the help system
- The usefulness of the system in helping students to learn fractions
- Suggestions for further improvement

Reponses to all the above questions are positive (cf. He, 2003). The test data obtained is however insufficient for assessing the effect of the system in helping the students learn the basic concepts of fractions and the skills required to answer fraction related questions due to the limited number of students.

Further Work

Future work will include a full evaluation of the effectiveness of the system in tutoring students fractions. This will require persuading more schools to use the system and the collection of test data from students. Analysis of the data obtained will provide the necessary information for assessing the effectiveness of the system in tutoring fractions. If the system is proved to be effective, more schools should be encouraged to use the system.

Although the present fraction item bank contains many of the question types of fraction related items, incorporation of more items of additional question types is required in order to make the system to cover as many fraction question types as possible. Further work on item analysis is also required in order to make sure that the items contained in the system are effective items.

That is, these questions should be typical fraction questions containing the most important fraction concepts and requiring specific skills to answer.

At the present, although most of the help topics contain animated movies for illustrating the various processes involved in representing fraction concepts and skills for answering fraction related questions, some of them do not have animated movies. There is potential to include animations in those help topics to make the relevant concepts or skills easier to understand. Further refinement of some of the existing animated movies may also be required. In accordance with the extension of items in the item bank, the development of new help topics will also be required. The new help topics may also require the creation of new animated movies.

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References

Abdullah, S. (1999) Premodelling for Examination Revision through Adaptive Testing http://www.cogs.susx.ac.uk/lab/hct/hctw99/download/ps/sophiana.ps.

Alpert, S.R., Singley, M.K. and Fairweather, P.G. (1999) Deploying Intelligent Tutors on the Web: An Architecture and an Example. *International Journal of Artificial Intelligence in Education* **10**: 183-197.

Anderson, J.R. (1983) *The Architecture of Cognition*. Cambridge, MA: Harvard University Press.

Anderson, J.R. (1993) *Rules of the Mind*. Hillsdale, NJ: Erlbaum.

Anderson, J.R., Corbett, A.T., Koedinger, K.R.and Pelletier, R. (1995) Cognitive tutors: Lessons learned. *The Journal of the Learning Sciences* **4**: 167-207.

Archer, R.P., Tirrell, C.A. and Elkins, D.E. (2001) Evaluation of an MMPI--a short form: implications for adaptive testing. *Journal of Personality Assessment* **76**: 76-89.

Brown, A. and Iwashita, N. (2002) Language background and item difficulty: the development of a computer-adaptive test of Japanese. *System* **24**: 199-206.

Derry, S.J. (1990) Learning Strategies for Acquiring Useful Knowledge. *In* Dimensions of Thinking and Cognitive Instruction (ed. by B. Jones and L. Idol). Hillsdale, NJ: Erlbaum, 347-379.

Fox, S. and Schwartz, D. (2002) Social desirability and controllability in computerized and paper-and-pencil personality questionnaires. *Computers in Human Behavior* **18**: 389-410.

Goldberg, M.W., Salari, S; and Swoboda, P. (1996) World Wide Web - Course tool: An environment for building WWW-based courses. *Computer Networks and ISDN Systems* **28**: 1219-1231.

Grow. G.O. (1996) "Serving the Strategic Reader: Reader Response Theory and Its Implications for the Teaching of Writing," an expanded version of a paper presented to the Qualitative Division of the Association for Educators in Journalism and Mass Communication. Eric Documentation Reproduction Service No. ED 406 644.

He, Q. (2003) The development of a fraction testing and tutoring system. Unpublished MSc thesis, University of Northumbria at Newcastle, UK.

He, Q. and Tymms, P.B. (2004) The development of a computer assisted design, analysis and testing system for analysing students' performance. *2004 CAA Conference Proceedings*: 165-175. University of Loughborough, UK.

Hueyching, J.J. (1996) The impact of learners' pathways on learning performance in multimedia Computer Aided Learning. *Journal of Network and Computer Applications* **19**: 367-380.

Koedinger, K.R. (1998) Intelligent Cognitive Tutors as Modeling Tool and Instructional Model. *Position Paper for the NCTM Standards 2000 Technology Conference* June 5-6, 1998.

Koedinger, K.R., Anderson, J.R., Hadley, W.H. and Mark, M.A. (1997) Intelligent tutoring goes to school in the big city. *International Journal of Artificial Intelligence in Education* **8**: 30-43.

Lee, F.L. and Heyworth, R.M. (2000) Electronic Homework. *Journal of Educational Computing Research* **22**: 171-186.

Lilley, M. and Barker, T. (2003) An evaluation of a Computer Adaptive Test in a UK university context. *2003 CAA Conference Proceedings*: 171-182. University of Loughborough, UK.

Lilley, M., Barker, T. and Britton, C. (2004) The generation of automated student feedback for a Computer-Adaptive Test. *2004 CAA Conference Proceedings*: 187-201. University of Loughborough, UK.

Nwana, H.S. (1993) The Anatomy of FITS: A Mathematic Tutor. *In* Mathematical Intelligent Learning Environments (ed. By H.S. Nwana). Oxford, England: Intellect, 79-109.

Rand, R. (2003) Visual Fractions. http://www.visualfractions.com/.

Sleeman, D.H. and Brown, J.S. (1982) *Intelligent Tutoring Systems.* London: Academic Press.

Thelwall, M. (2002) Computer-based assessment: a versatile educational tool. *Computers and Education* **34**: 37-49.

Tonidandel, S., Quiñones, M.A. and Adams, A.A. (2002) Computer-adaptive testing: the impact of test characteristics on perceived performance and test takers' reactions. *The Journal of Applied Psychology* **87**: 320-332.

Wood H., Wood, D. and Cheng, P. (2001) The development of contingent tutoring systems (CTSs). http://www.psychology.nottingham.ac.uk/research/credit/projects.