Designing Game-Based Interactive Mathematics Learning Environments for Children

by

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Abstract

With the tremendous growth of the use of computers in schools, sound research is needed on how to design interactive learning environments that effectively help children by promoting reflective cognition and better learning. The research described in this thesis addresses the following questions in designing interactive mathematics learning environments for children: a) How should a learning environment motivate children to explore the underlying mathematical concepts? b) How should the user interface be designed to support children’s learning of mathematical concepts? c) What are some design features that are effective in promoting reflective cognition and better learning? d) How should a learning environment meet children’s affective needs? What are some design features that can make children’s learning of mathematics more enjoyable?

Bubble Puzzle, a game-based interactive learning activity aimed at assisting elementary school children in understanding fractions was developed. Techniques such as visual feedback and scaffolding were used in the design to promote reflective cognition. Two studies with 47 elementary school children were conducted to evaluate the educational effectiveness and the design features of Bubble Puzzle. It was found that playing the game helped children gain a better understanding of the underlying mathematical concepts, and led to statistically significant improvements on test scores. The results suggest that Bubble Puzzle provided a motivating learning environment, and that the entertainment features of the game matched children’s interests and were conducive to children’s enjoyment of the learning activity.
Contents

Abstract.................................................................................................................................................. ii
Contents .................................................................................................................................................. iii
List of Tables .......................................................................................................................................... vi
List of Figures ......................................................................................................................................... viii
Acknowledgements ............................................................................................................................. ix
1 Introduction ........................................................................................................................................ 1
2 Research Context ............................................................................................................................... 4
  2.1 Educational Software ................................................................................................................... 4
  2.2 Electronic Games .......................................................................................................................... 8
  2.3 HCI Issues in Educational Software for Children ........................................................................ 10
3 Bubble Puzzle .................................................................................................................................... 13
  3.1 Introduction and Background ....................................................................................................... 13
  3.2 Design Issues to Consider ........................................................................................................... 15
    3.2.1 The Game Activity ................................................................................................................ 15
    3.2.2 The Educational Content ..................................................................................................... 16
    3.2.2.1 Mathematical Objectives .............................................................................................. 16
    3.2.2.2 Representation of Concepts ......................................................................................... 17
  3.3 The Initial Prototype ...................................................................................................................... 17
    3.3.1 The Initial Design .................................................................................................................. 18
    3.3.2 The Preliminary Evaluation .................................................................................................... 19
      3.3.2.1 Subjects ....................................................................................................................... 19
      3.3.2.2 Setting and Procedure .............................................................................................. 20
      3.3.2.3 Results ....................................................................................................................... 20
  3.4 Refined Bubble Puzzle Design ...................................................................................................... 21
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.4.1 The Game Activity</td>
<td>21</td>
</tr>
<tr>
<td>3.4.2 Representations of Mathematical Concepts</td>
<td>22</td>
</tr>
<tr>
<td>3.4.3 The User Interface</td>
<td>23</td>
</tr>
<tr>
<td>3.4.3.1 The Level Chooser</td>
<td>23</td>
</tr>
<tr>
<td>3.4.3.2 The Game Screen</td>
<td>24</td>
</tr>
<tr>
<td>3.4.3.3 The Game Control</td>
<td>26</td>
</tr>
<tr>
<td>3.4.4 Scaffolding</td>
<td>26</td>
</tr>
<tr>
<td>3.4.4.1 Order of Levels</td>
<td>26</td>
</tr>
<tr>
<td>3.4.4.2 Visual Transition</td>
<td>28</td>
</tr>
<tr>
<td>3.4.4.3 Color Hint and Falling Threshold</td>
<td>28</td>
</tr>
<tr>
<td>3.4.5 Rewards and Feedback</td>
<td>30</td>
</tr>
<tr>
<td>3.4.6 Help Screens</td>
<td>30</td>
</tr>
<tr>
<td>3.4.7 Entertainment Elements</td>
<td>31</td>
</tr>
<tr>
<td>4 Pilot Study</td>
<td>33</td>
</tr>
<tr>
<td>4.1 Subjects</td>
<td>33</td>
</tr>
<tr>
<td>4.2 Setting and Procedure</td>
<td>34</td>
</tr>
<tr>
<td>4.3 Results</td>
<td>34</td>
</tr>
<tr>
<td>4.3.1 Usability of the Game</td>
<td>35</td>
</tr>
<tr>
<td>4.3.2 Test Materials</td>
<td>36</td>
</tr>
<tr>
<td>4.3.3 Procedures</td>
<td>37</td>
</tr>
<tr>
<td>5 Study Design and Methodology</td>
<td>38</td>
</tr>
<tr>
<td>5.1 Subjects</td>
<td>39</td>
</tr>
<tr>
<td>5.2 Sources of Data</td>
<td>39</td>
</tr>
<tr>
<td>5.2.1 Tests</td>
<td>39</td>
</tr>
<tr>
<td>5.2.1.1 Fraction Knowledge Tests</td>
<td>39</td>
</tr>
<tr>
<td>5.2.1.2 Poison Puzzle Tests</td>
<td>40</td>
</tr>
<tr>
<td>5.2.1.3 Trial Run of Tests</td>
<td>41</td>
</tr>
<tr>
<td>5.2.2 Questionnaires</td>
<td>42</td>
</tr>
<tr>
<td>5.2.3 Video</td>
<td>43</td>
</tr>
<tr>
<td>5.2.4 Direct Observations</td>
<td>43</td>
</tr>
<tr>
<td>5.2.5 Interviews</td>
<td>43</td>
</tr>
<tr>
<td>5.3 Design</td>
<td>44</td>
</tr>
<tr>
<td>5.4 Setting and Procedure</td>
<td>45</td>
</tr>
<tr>
<td>6 Results and Discussion</td>
<td>47</td>
</tr>
<tr>
<td>6.1 Results on Achievement</td>
<td>47</td>
</tr>
<tr>
<td>6.1.1 Domain Learning Outcomes</td>
<td>48</td>
</tr>
<tr>
<td>6.1.1.1 Overall Achievement Outcomes</td>
<td>48</td>
</tr>
<tr>
<td>6.1.1.2 Finer-Grained Achievement Outcomes</td>
<td>49</td>
</tr>
</tbody>
</table>
List of Tables

Table 3.1 Game control of the initial prototype of Bubble Puzzle. ......................... 18
Table 3.2 List of representations of fractions. ......................................................... 23
Table 3.3 The Bubble Puzzle buttons. ................................................................. 25
Table 3.4 List of level groups. ............................................................................. 27
Table 3.5 List of bubble color types. ................................................................. 29
Table 3.6 List of difficulty setting in each level group......................................... 30
Table 5.1 Number of questions in the Fraction Knowledge Tests..................... 40
Table 5.2 Schedule for sessions in Study A....................................................... 45
Table 6.1 Descriptive statistics for the Fraction Knowledge Tests..................... 49
Table 6.2 Paired samples t-tests for the overall scores of Fraction Knowledge Tests. .................................................................................. 49
Table 6.3 Paired samples t-tests for equivalent fraction question scores.......... 50
Table 6.4 Paired samples t-tests for simple operation question scores............... 51
Table 6.5 Paired samples t-tests for complex operation question scores.......... 52
Table 6.6 The distribution of children's responses to the question: Bubble Puzzle helped me learn about fractions (N=47). ..................................................... 53
Table 6.7 Paired samples t-tests for the Poison Puzzle Tests and the number of levels passed in the Poison Puzzle game phases.............................. 55
Table 6.8 Children's responses regarding the design features for enhancing learning (N=47)........................................................................................................................................56

Table 6.9 The distribution of children's responses to the question about which setting for color hints helped them learn the most (N=47).........................................................................................................................................56

Table 6.10 Children's responses to questions about the design features for motivation and entertainment (N=47).........................................................................................................................................57
List of Figures

Figure 3.1 A Poison Puzzle screen ......................................................... 14
Figure 3.2 A screen of the initial prototype of Bubble Puzzle .................. 19
Figure 3.3 A Bubble Puzzle screen ....................................................... 22
Figure 3.4 The Level Chooser screen ................................................... 24
Figure 3.5 Help screen for level 34 ....................................................... 31
Figure 4.1 An example question in the Pilot Study pre- and post-tests ...... 36
Figure 5.1 Example questions in the Poison Puzzle Tests ....................... 41
Figure 6.1 Mean scores on the Fraction Knowledge Tests (N=47) .......... 49
Figure 6.2 Mean scores on equivalent fraction questions (N=47) .......... 50
Figure 6.3 Mean scores on simple operation questions (N=47) .......... 51
Figure 6.4 Mean scores on complex operation questions (N=47) .......... 52
Figure 6.5 Mean scores on the Poison Puzzle Tests and the number of levels passed in the Poison Puzzle game phases (N=12) ......................................................... 54
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Chapter 1

Introduction

“In traditional classrooms, students typically have very little time to interact with materials, each other, or the teacher. Moreover, students often must wait days or weeks after handing in classroom work before receiving feedback. In contrast, research suggests that learning proceeds most rapidly when learners have frequent opportunities to apply the ideas they are learning and when feedback on the success or failure of an idea comes almost immediately” [Roschelle et al., 2000].

Research indicates that computer supported learning can encourage rapid interaction and feedback, can encourage students to spend extended periods on their learning task, and in some situations, can analyze each student’s performance and provide more timely and targeted feedback than the student typical receives in traditional classrooms [Schofield, 1995; Anderson et al., 1995; Roschelle et al., 2000]. Computer software has been viewed as a potential tool for helping students increase motivation, gain a deeper understanding of concepts and develop better problem solving skills [Sivin-Kachala and Bialo, 1999]. The use of computers in education has grown tremendously over the last
ten years. In order to understand how to maximize the use of computers in classrooms in terms of academic and social priorities, sound research in Computer Science, Education, Psychology, and related disciplines is needed.

Electronic games, more than any other interactive technology, have become a significant part of children's contemporary culture, yet they are rarely considered for their educational benefits. A remarkable feature of electronic games is their power to motivate. Common features of electronic games such as active participation, intrinsic and prompt feedback, challenging but achievable goals, and a mix of uncertainty and open-endedness, contribute to motivation. Motivation plays a central role in any learning activity [Dweck, 1986]. Thus, it is a logical step to try to take advantage of the motivating nature of electronic games by using this medium for educational purposes rather than simply for pure entertainment. Research indicates that well-designed computer games can meet some of the psychological needs of children and motivate them want to learn [Sedighian and Sedighian, 1996]. In addition, hardware advances in the last ten years have made possible the concept of computer-based edutainment - education in the form of entertainment - where learners can arrive at the goal of learning by having fun. However, creating educational computer games is not simply a matter of adding educational content to some kind of games. The software itself should be conceived as the result of evidence that the particular educational content can be effectively delivered in a computer game environment [Heo and Byun, 2001]. There are numerous issues in the design of educational computer games. Research in this area is quite recent and remains sparse. More guidelines and principles are needed by educational game designers in order to make their software more effective in enhancing learning.

Many students find learning mathematics difficult, and do not like studying mathematics. Sedighian [1997] states that the difficulty in helping students learn mathematics is twofold: one is to motivate them to want to spend time and engage in mathematical activities, the other is to aid them cognitively to construct mathematical knowledge. Some researchers suggest that computer games can be highly effective in
increasing children’s learning and enjoyment of mathematics [Klawe, 1998a; Randel, Morris, Wetzel and Whitehill, 1992].

This thesis presents the design and evaluation of a game-based interactive learning environment developed to assist students in enhancing their understanding of fractions. Questions addressed in this research include:

1. How should a learning environment motivate children to explore the underlying mathematical concepts?
2. How should the user interface be designed to support children’s learning of mathematical concepts?
3. What are some design features that are effective in promoting reflective cognition and better learning?
4. How should a learning environment meet children’s affective needs? What are some design features that can make children’s learning of mathematics more enjoyable?

This thesis includes seven chapters. Chapter 2 summarizes background research in educational software, electronic games, and human-computer interaction from a variety of disciplines that impact on the research presented in this thesis. Chapter 3 describes and discusses the design of a game-based interactive mathematics learning environment. Chapter 4 describes the Pilot Study conducted prior to two formal studies, which led to modifications of the activity and the planned formal study procedure. Chapter 5 details the research methods in two formal studies used to evaluate the pedagogical effectiveness of the design described in Chapter 3. Chapter 6 provides a detailed analysis and discussion of results of the research studies. Chapter 7 summarizes the research, and suggests some issues for future research.
Chapter 2

Research Context

This chapter reviews previous research related to educational software, electronic games, and human-computer interaction issues in educational software for children. It is necessary to integrate research findings from several domains to provide the foundation and background that led to the design of the game-based interactive mathematics learning environment for children described in Chapter 3.

2.1 Educational Software

Educational software first emerged in the 1960’s. Much of the school software used in those days was of the type referred to as Computer-Aided Instruction (CAI). In a CAI system, the author generates material to be presented by the computer, and the computer simply follows the explicit instructions of the author in the interaction with a student [Elsom-Cook and O’Malley, 1990]. CAI software usually offers some corrective
guidance, but the level of error diagnosis undertaken by the computer is minimal. Intelligent CAI or what is more commonly known as Intelligent Tutoring Systems (ITS) appeared in the 1970’s. ITS software monitors the pattern of errors made by the student, and attempts to model the student’s reasoning. That model is then used to select the most appropriate further tasks or instructions. Such a system is thus learning about the learner in order to teach [Light and Littleton, 1999]. Today’s common term for educational software is Interactive Learning Environments (ILE). Wilson [1992] states that Interactive Learning Environments “allow for the electronically integrated display and user control of a variety of media formats and information types, including motion video and film, still photographs, text, graphics, animation, sound, numbers and data. The resulting interactive experience for the user is a multidimensional, multisensory interweave of self-directed reading, viewing, listening, and interacting, through activities such as exploring, searching, manipulating, writing, linking, creating, juxtaposing and editing”.

“From the earliest days of the invention of the computer, there has been a promise that they would play a major role in education, from helping children to learn in the school and in the home, to helping adults acquire job training. Frankly, to date that potential has not been realized” [Soloway and Bielaczyc, 1996]. Studies [Kulik and Kulik, 1976] have shown that using computer-aided instruction can reduce learning time by up to 30% and improve test scores by up to 10%, when compared with human-taught courses. In addition to academic achievements, classroom computer activities have been found to lead to higher levels of student interaction compared to non-computer activities [Nastasi and Clements, 1993]. Some researchers indicate that computers have been shown to raise children’s motivation and engagement. Krendl and Lieberman [1988] argue that students will spend more time working on computer activities than on non-computer activities. Some researchers, however, have questioned the relevance of using computers with children in the classroom setting. Clark [1983] argues that a computer only delivers content and does not itself affect achievement. Critics continue to demand “hard evidence to show that putting children on computers can increase the literacy rate,
raise test scores, improve student retention, and indeed, give an overall boost to educational institutions" [Rist, 1991].

**Interactive Learning Environments**

The level of interactivity in traditional CAI and ITS tends to be low compared to ILE. Their basic goal is only to teach specific content knowledge and skills. Because of their limited scope, they have only been moderately successful [McGrenere, 1996]. Soloway and Bielaczyz [1996] suggest that educational software needs to broaden its scope and look at issues of communication, inquiry, reasoning, and metacognitive skills in order to meet the needs of the 21st century. ILE systems combine features from a wide variety of systems including CAI, ITS, e-books, hypermedia systems, simulations and microworlds, to provide a high level of interactivity as well as learner control [Murphy, 1997].

Giardina [1992] suggests that learner control, intelligence and adaptability are the three central themes in interactive learning environments. Learner control is the degree to which a learner can direct his/her own learning experience [Shyu and Brown, 1992]. Doherty [1998] argues that ILE systems should provide learners with control over depth of study, range of content, number and type of delivery media, and time spent on learning. With these options, learners can tailor the learning experience to meet their specific needs and interests. For this reason, learner control is “not an unitary construct, but rather a collection of strategies that function in different ways depending upon what is being controlled by whom” [Ross and Morrison, 1989]. In order to provide intelligence and adaptability, interactive learning environments need to monitor the interactions of the user and react accordingly. Adaptive feedback is effective in enhancing learning [Norman, 1993; Tsybenko and Bykov, 1997]. A system's ability to provide adaptive feedback demands a very sophisticated design because the system must not only be capable of noting the user's actions but also be capable of interpreting and then reacting or adapting to them [Murphy, 1997]. The interpretation is a complex process involving transforming the user's actions into a representation of his knowledge.
which must be overlaid on the representation of the system's knowledge [Duchastel, 1992].

Scaffolding is another technique used for ILE systems design [Soloway, Guzdial and Hay, 1994]. It is a means of supporting the learner so that “more support is provided initially, but as the learner acquires the necessary knowledge and skills, the support fades, leaving the learner in control” [McGrenere, 1996]. Based on types of support given, Winnips and McLoughlin [2000] categorize the software scaffolding as following:

- Providing examples: these examples should not only focus on products, but also on a process.
- Helping students, by giving away parts of the solution.
- Providing a model for design, or a structure to design in.
- Cueing/hinting: helping students with a solution by providing a hint or cue to a possible path of the solution.
- Coaching comments: these comments are intended for motivation, providing feedback and advice on performance, and provoking reflection.
- Asking questions, pointing out weaknesses, asking for a motivation, in order to enhance reflection.
- Metacognitive support: stating why the above types of support are given, in order to model the type of metacognition that experts would use.
- Providing a timeline, with fixed dates and goals built in. This structure could be present, to help students appearing to be very goal directed to build in multiple evaluation moments into the actual experience of studying.

Scaffolding has been well-established as an effective means of supporting learning [Collins, 1996; Rogoff, 1990]. Building scaffolding into software offers “the opportunity to provide for diversity through individualized support that accommodates learners of different skills, backgrounds, and learning styles, and to support growth by making more powerful functionality available as the learner develops expertise” [Jackson, Krajcik and Soloway, 1998].
Interface style is another important factor in ILE design [Klawe, 1998a]. Recent HCI research in problem solving and learning indicates that interfaces with the lowest cognitive effort may not be the most educationally effective [Sedighian, 1998; Holst, 1996]. Sedighian [1998] suggests that interfaces that involve direct concept manipulation are better for promoting reflective cognition than those that manipulate an object that is being used to illustrate the concept. Holst [1996] argues that difficult or awkward interfaces are better than intuitive or easy interfaces for directing the learner’s attention. Sedighian and Klawe [1996] provide an interface strategy for promoting reflective cognition. It is based on three interface elements: “a) an educationally appropriate representation, b) an interaction protocol that naturally shifts children’s attention from intuitive interaction to one that focuses on the structure and operation of the representation, and c) a gradual elimination of feedback and/or components of the representation so that children are required to assume increasing cognitive responsibilities”.

### 2.2 Electronic Games

The video game industry has experienced tremendous growth in the last twenty years. Playing electronic games has become a common activity among children. Research has focused on explaining why children love playing these games and what the effects of electronic game playing are on children's social, cognitive and emotional well-being. Motivational researchers [Lepper and Malone, 1987; Malone, 1981; Malone and Lepper, 1987] have offered the following characteristics common to all electronic games:

- **Challenge**: a game should have clear goals but the attainment of these goals should be uncertain. Goals should neither be too easy nor impossible to achieve. The goal should be achievable in a number of ways, and the player’s path through a game should not be predictable. Games should include performance feedback such as how close the player is to achieving the goal.
• **Fantasy**: this is used to encourage players to imagine that they are completing the activity in a context in which they are really not present. Games should provide several fantasies so that different people can select fantasies that are personally appealing.

• **Curiosity**: a game’s environment should provide an optimal level of informational complexity. Games should be novel and surprising, and be neither too simple nor totally incomprehensible.

• **Control**: a game should provide effective control so that the individual feels completely in control of the activity.

Some researchers indicate that games are not just a diversion to children, but an integral part of their social and cultural lives [Rieber, 1996; Chick and Barnett, 1995]. For example, children often evaluate their status in a peer group based on their interaction in games [Rieber, 1996].

Many researchers have looked at the potential of electronic games for educational purposes. Randel, Morris, Wetzel and Whitehill [1992] examined 68 studies on the difference between game-based and conventional instruction. Students reported more interest in the game activities than in more conventional activities. Most of the studies found the academic achievements of game-based instruction equivalent to or better than that of traditional classroom instruction. The results also suggested that the use of computer games may be more useful in mathematics and physics learning than in the area of social sciences.

Klawe [1998a] also suggested that computer games can be highly effective in increasing children’s learning and enjoyment of mathematics. She notes that the extent of the effectiveness depends on the software design and how the games are used. In game design, she indicates that the primary issue is ensuring that students recognize, think about and value the mathematics embedded in the computer game. Other factors such as activity, feedback, interface styles and scaffolding are also important issues in game design. In game use, Klawe suggests three factors to be particularly important in
focusing students' attention on mathematics: teacher expectations, supporting activities that integrate the games with the other ways mathematics is being learned in the classroom, and collaborative play.

2.3 HCI Issues in Educational Software for Children

Human-Computer Interaction (HCI) is "the study of how people communicate and interact with computer systems and how to design, build, and evaluate technologies to facilitate those interactions" [Inkpen, 1997]. HCI is a complex and highly interdisciplinary area of research. The main contributing disciplines include Computer Science, Cognitive Psychology, Social and Organizational Psychology, Ergonomics and Human Factors.

Usability is a central concept in HCI. It is defined in ISO 9241-11 as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use". Nielsen [1993] describes five characteristics of usability:

- **Ease of learning**: the interface should be designed to allow users who have never seen it before to learn to use it quickly to succeed in accomplishing basic tasks.
- **Efficiency of use**: the interface should be designed to allow rapid accomplishment of tasks for more experienced users.
- **Memorability**: the interface should be easy to remember, so that the casual user is able to return to the system after some period of not having used it, without having to learn everything all over again.
- **Error frequency and severity**: the interface should be designed to minimize the number and severity of errors, and allow for quick error recovery.
- **Subjective satisfaction**: the interface should be pleasant to use, so that users are subjectively satisfied when using it.
Because the purpose educational software is not just task performance but rather the promotion of learning, its usability is not related directly to the efficiency and effectiveness of the task execution, but to the effectiveness and efficiency of learning that should occur during this activity. Researchers have developed some guidelines with respect to the usability of educational software in order to help designers produce more usable systems [Sharples and Beale, 2002; Squires and Preece, 1999]. Barker and King [1993] provide some factors which their research suggests are of key importance to successful educational software. These factors include: quality of end-user interface, engagement, interactivity, tailorability, appropriateness of multimedia mix, mode and style of interaction, quality of interaction, user learning styles, adequacy of ancillary learning support tools and suitability for single user/group/distributed use. Mayes and Fowler [1999] also discuss some general design issues related to usability in three general kinds of educational software. However, the interface design of educational software is an extremely complex topic that goes beyond the usability during task performance because of the need to allow and support learning. Thus, general usability criteria and guidelines that are useful, remain quite limited. In order to examine usability that fulfils learning purposes, a wide range of methods should be used in the evaluation. Dimitracopoulou [2001] states that the usability evaluation of educational software should provide information with significant interpretative value, and should be applied not only during the whole development lifecycle but also during the postproduction period. Dimitracopoulou suggests that repeated informal and formal evaluation methods should be used in laboratory as well as in real school contexts.

User-Centered Design (UCD) is a widely accepted HCI methodology for designing usable applications. UCD focuses on the needs of the user and meeting those needs in the interface [Norman and Draper, 1986]. It offers a collection of tools and methods for planning, iterative development and evaluation, and fosters a tight evaluation feedback loop to assure that the deficiencies are identified and corrected at an early stage of the development life-cycle [Dimitracopoulou, 2001]. Learner-Centered Design (LCD) offers a new perspective in which HCI interaction principles are combined with educational interaction support [Guzdial et al., 1995]. Because children are becoming
an increasing portion of the computer market, it is becoming important to apply
Learner-Centered Design theory to more specific topics. As a unique group of learners,
children's needs and interactions are different from those of adults. Inkpen [1997]
discusses three aspects of the difference:

- **Motor skill development:** children's motor skills are not fully developed. For
  example, some researchers have found that children have difficulty performing
  mouse operations that require sustained pressure on the mouse button, thus
  point-and-click interaction style is better for children than the drag-and-drop
  interaction style [Inkpen, Booth, and Klawe, 1996; Stromme 94].

- **Cognitive differences:** children's cognitive capabilities are different from those
  of adults. Children may have physical or cognitive difficulty using adult
  interaction techniques.

- **Experiential differences:** children have different experiences and perspectives
  from adults. For example, common adult metaphors in software may not make
  sense to children. Child-appropriate metaphors should be used in software for
  children.

In order to make children's educational software effective, designers should take a
child-centered view. Software should be designed in a way that addresses children's
 cognitive, affective, and behavioral needs [Sedighian, 1998]. Much of the existing
research focuses on conceptual aspects of software, such as how to help children learn
particular subject matter, or how to improve their thinking and problem solving skills
[e.g., De Corte, Kinn, Mandl and Verschaffel, 1992; Duffy, Lowyck and Jonassen, 1993;
Klein, 1985; Forman and Pufall, 1988]. There is little research on how to design
effective educational interaction [e.g., Soloway, 1996; Sedighian and Klawe, 1996;
Holst, 1996]. More research in this area should be conducted in order for children to be
able to use these systems effectively.
Chapter 3

Bubble Puzzle

3.1 Introduction and Background

EGEMS, Electronic Games for Education in Math and Science (URL: http://www.cs.ubc.ca/labs/egems), which was founded in 1992, is an interdisciplinary group of computer science and education researchers, professional game developers, children and teachers, who are collaborating on the research and development of educational software. Phoenix Quest is an adventure computer game developed by EGEMS, which includes a set of puzzles designed to encourage children of ages 9-14 to explore mathematical concepts. The mathematical puzzles cover a wide range of concepts: fractions, ratios, negative numbers, rectangular and polar coordinates, graph algorithms, logic, and number sequences. Poison Puzzle is one of the mathematical puzzles in Phoenix Quest, which is intended to help students exercise their knowledge of fractions. Figure 3.1 shows a screen of Poison Puzzle which contains four questions.
For each question, the player collects ingredients to build fractions along the bottom of the screen, trying to make the total fraction the same as the target fraction shown in the rectangle frame.

Classroom evaluation showed that playing Poison Puzzle could help students gain a better mastery of fraction knowledge. However, feedback from some of the target users, namely students in grades 4 to 6, indicated that Poison Puzzle was too hard for them because of insufficient prior fraction knowledge. For example, to solve the question in Figure 3.1, students require the following skills and knowledge: recognizing equivalent fractions, building and reducing fractions, reduction of fractions to a common denominator, and adding and subtracting fractions. Fraction concepts and skills are introduced in most Canadian school districts at about grade 4 and developed through grade 8. Thus many students in grades 4 to 6 have not yet mastered all of the necessary knowledge to solve the kind of question posed in Poison Puzzle. Unfortunately, Poison Puzzle does not include activities that help students develop a good understanding of these fraction concepts.
This chapter describes the design of a new puzzle, Bubble Puzzle, a game-based interactive learning environment developed to assist students in enhancing their understanding of fractions, and to increase their ability to solve the questions in Poison Puzzle. In Bubble Puzzle, fractions are presented using typical visual representations. The difficulty of the concepts and cognitive challenge gradually increase as the student progresses through the levels of the game.

3.2 Design Issues to Consider

3.2.1 The Game Activity

An important aspect of teaching a subject is the selection of an appropriate supporting activity [Sedighian, 1998]. In our case, the game activity is intended to provide a motivating environment for children to engage in mathematical learning. It is important to design a game activity which matches children’s interests, while at the same time motivates them to explore the underlying mathematical concepts embedded in the game. Several issues were considered in the design of the game activity:

1. The activity should be designed as a computer game with an interface suitable for children aged 9 to 14.

2. The game activity must support the learning of the educational content, and stimulate reflection about the mathematical concepts. It should be designed to prevent children from only paying attention to the entertainment elements in the game, while ignoring the underlying mathematical concepts.

3. The game activity must carefully balance the level of challenge and frustration. “A game can be made so frustrating that the player will soon become disillusioned and simply abandon it” [Gamasutra, 2002]. “If a game is to provide a continuing challenge to the player, it must also provide a continuing motivation to play. It must appear to be winnable to all players, the beginner and the expert” [Crawford, 1982].
4. The game activity should have a goal or a set of intermediate goals to achieve. Activities with explicit goals work well for most students [Klawe, 1998b]. These goals create a sense of mission in children, and it is important that accomplishing the goals can provide them with a sense of success.

5. The intermediate goals should progressively become more challenging: in order to succeed, students should need to continuously increase and refine their understanding of the embedded mathematical domain.

6. The game activity should provide adaptive feedback and rewards. Feedback helps players understand their progress, and evaluate their choices and decisions. Progressively reducing visual or auditory feedback in a task can require students to gradually take on greater cognitive responsibility. Rewards such as scoring and sound effects can be effective in increasing students' motivation.

7. Instructional modules should be designed to support more structured and directed styles of learning. These components help children refine and increase their mathematical knowledge from more formal explanations.

3.2.2 The Educational Content

The educational content of the game is concepts and skills related to fractions. The representations of fractions used in the game are based on those in current mathematics textbooks in order to make the game consistent with the children's other learning materials.

3.2.2.1 Mathematical Objectives

A list of the mathematical objectives is presented below. The game is intended to help children:

1. Understand the basic concept of fraction.
2. Understand the concept of equivalent fraction, and convert one fraction to an equivalent fraction by building or reducing.
3. Add or subtract two fractions with the same denominator (we call this a simple operation).

4. Add or subtract two fractions with different denominators (we call this a complex operation).

3.2.2.2 Representation of Concepts

It is important to represent the mathematical concepts in an appropriate way because representation greatly influences the educational effectiveness of the game. Klawe [1998b] suggests that a representation should reflect what the game designers want the student to think about, and that using the same representation as used in other accompanying modes of mathematics education such as textbook and lectures, will help students transfer and integrate understanding between the different modes.

3.3 The Initial Prototype

Early in the prototype design phase we looked for a suitable computer game to use for the faction-learning environment. We expected the game to support the integration of the mathematical concepts, and meet the activity design criteria described in Section 3.2.1. A color bubbles game in which players use the bubble color to match bubbles [Yang, 2000] was selected for the activity design. The mathematical content was integrated into the game by randomly assigning each bubble a fraction. In order to do a preliminary evaluation of the appropriateness of the game activity, a simple stand-alone Bubble Puzzle prototype was created in JavaScript. The sole mathematical content in this prototype was recognition of equivalent fractions.
3.3.1 The Initial Design

The initial prototype contains a single level. When the game begins, the game screen shows a rectangle playing field. A horizontal line called the base line divides the playing field into two areas as shown in Figure 3.2. A group of bubbles called target bubbles are stuck together at the top of the upper area. One bubble called the bullet bubble is located at the bottom of the lower area. Each bubble contains a randomly assigned fraction. The player controls a bubble gun that can shoot the bullet bubble into the upper area. The game is controlled by three keys as shown in Table 3.1. The bubble gun can be rotated left and right. The dotted line indicates the direction that the bullet bubble will go. Bullet bubbles can be bounced off the left and right sides of the playing area like pool balls. The player's goal is to completely empty the upper area of bubbles. When a bullet bubble is shot so that it hits a matching target bubble, i.e., one with an equivalent fraction to that of the bullet bubble, the two matched bubbles disappear from the upper area. In addition, any target bubbles hanging from the matched target bubble also disappear. Thus the player can sometimes remove many bubbles from the screen with a single, well aimed, shot. If the bullet bubble hits a target bubble that does not match, the bullet bubble stops moving and changes into a target bubble. Thus, the number of target bubbles left to shoot increases. As soon as a bullet bubble is shot, the bubble gun is reloaded with a new bullet bubble. The player loses the game as soon as the number of target bubbles grows sufficiently large that a target bubble touches the base line.

<table>
<thead>
<tr>
<th>Function</th>
<th>Keyboard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotate bubble gun left</td>
<td>← key</td>
</tr>
<tr>
<td>Rotate bubble gun right</td>
<td>→ key</td>
</tr>
<tr>
<td>Fire bubble gun</td>
<td>↑ key</td>
</tr>
</tbody>
</table>

Table 3.1 Game control of the initial prototype of Bubble Puzzle.
3.3.2 The Preliminary Evaluation

A classroom evaluation of the initial prototype was conducted to provide a preliminary assessment of the usability of the game in terms of children’s reactions to its design. This evaluation helped us refine the game design. It also factored into the design of the later formal evaluations.

3.3.2.1 Subjects

The preliminary evaluation was conducted at Maple Grove Elementary School, a public elementary school, located in an upper-middle-class neighborhood of Vancouver, British Columbia, Canada. The participants were twenty grade 6 children (8 girls and 12
boys) from a single class. All children were volunteers, who had received written permission from their parents.

3.3.2.2 Setting and Procedure

Four IBM-compatible laptop computers were set up in the computer laboratory of the school. At most 8 students took part in the study in any one session. With a pair of students assigned to each computer in each session, the researchers first gave a 5-minute orientation to the students, introducing the task and interface of the game. Students then played the prototype for approximately 20 minutes. During their playing, researchers observed children’s interactions with the game interface, listened to their conversations, and paid attention to which design features attracted them and at what point their interest diminished. After the children finished playing, they were asked to describe their opinion about the game.

3.3.2.3 Results

The results of the evaluation were encouraging: the game design seemed to be very appealing to children, both boys and girls. The results indicated that the prototype provided a fun game environment for students, while making them think about fractions. Our observations identified two design features as particularly attractive. The first was that bullet bubbles could reflect off the sides of the playing field so that a bullet bubble could reach a target bubble after several bounces. This seemed to make the game more fun, while introducing some concepts about angles and reflection. The second was that when a target bubble disappeared, all bubbles hanging below it would disappear too. Children often became very excited when they succeeded in removing several bubbles with one well-planned shot.

The evaluation also identified some problems in the user interface:

1. The keyboard control was not convenient for players. It was slow and imprecise.
2. The shortness of the dotted line indicating the firing direction caused players to miss intended targets because they could not accurately estimate the trajectory that would be taken by the bullet bubble.

3. The game screen was too small. The bubbles were not large enough to show fractions clearly.

We also received design suggestions to make winning more feasible:

1. In order to provide more opportunities to recover from almost certain losses, students suggested the additional special “wild” bullet bubbles which could match any target bubble.

2. Because the fractions on bubbles were generated randomly, occasionally no target bubble would be equivalent to the bullet bubble. In this case, the player had to shoot the bullet bubble somewhere to become a new target bubble. To help players better plan where to place the bullet bubble in such cases, it was suggested that the game show information about the next bullet bubble to appear.

3.4 Refined Bubble Puzzle Design

Based on the results of the preliminary evaluation of the initial prototype, we refined the design, and implemented a more sophisticated prototype of Bubble Puzzle in C++. Bubble Puzzle was built as a stand-alone game for research purposes, but closely followed the puzzle format of Phoenix Quest so that it could easily be integrated into Phoenix Quest when the research was completed. This section presents the refined Bubble Puzzle design.

3.4.1 The Game Activity

The refined Bubble Puzzle (shown in Figure 3.3) uses the same game activity as the initial prototype, in that players attempt to clear the top playing area of bubbles by
hitting a matching target bubble with the bullet bubble. The refined version has many levels, and the type of matching to be done depends on the level. For example, in level 22 (see Figure 3.3), the bullet bubble contains the sum or difference of two fractions with the same denominator, whereas the target bubbles contain simple fractions. As the player progresses through the levels, the matching tasks engage the player in increasingly challenging concepts and operations.

![Figure 3.3 A Bubble Puzzle screen.](image)

**3.4.2 Representations of Mathematical Concepts**

Depending on which concept is being presented, the fractions have different representations such as lowest terms or simple operation expression. The representations used in the game are the same as those in other common modes of
mathematics learning such as textbooks. Table 3.2 shows the six different representations used in the game.

<table>
<thead>
<tr>
<th>Bubble Type</th>
<th>Example</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part-Whole</td>
<td><img src="image1.png" alt="Example" /></td>
<td>An equal-partitioned shape; the shaded portion indicates the fraction.</td>
</tr>
<tr>
<td>Lowest Terms</td>
<td><img src="image2.png" alt="Example" /></td>
<td>A fraction in lowest terms.</td>
</tr>
<tr>
<td>Non-Lowest Terms</td>
<td><img src="image3.png" alt="Example" /></td>
<td>A fraction not in lowest terms.</td>
</tr>
<tr>
<td>Simple Operation</td>
<td><img src="image4.png" alt="Example" /></td>
<td>A simple operation expression.</td>
</tr>
<tr>
<td>Complex Operation</td>
<td><img src="image5.png" alt="Example" /></td>
<td>A complex operation expression.</td>
</tr>
<tr>
<td>Wild</td>
<td><img src="image6.png" alt="Example" /></td>
<td>A blank fraction that players fill with any fraction desired.</td>
</tr>
</tbody>
</table>

Table 3.2 List of representations of fractions.

3.4.3 The User Interface

3.4.3.1 The Level Chooser

The first screen of Bubble Puzzle is the Level Chooser screen which contains 50 level icons (see Figure 3.4). There are 50 levels that contain different fraction concepts and degrees of challenge. Players are allowed to attempt levels in any order and replay all levels an unlimited number of times. This is a design feature applied in all puzzles in Phoenix Quest. Klawe [1998a] notes that there are two reasons for this feature: first,
repeated requests for this feature were received from students during classroom evaluations of Phoenix Quest, and second, repeated play of levels allows students to try many examples of each level of problem.

Figure 3.4 The Level Chooser screen.

### 3.4.3.2 The Game Screen

When a level is chosen and the Start Puzzle button is clicked, the game begins. Figure 3.3 shows a game screen in level 22. The Bubble Puzzle game screen consists of three major components. The playing field is a black rectangular area located in the center of the screen. A horizontal red line called the base line divides the playing field into two parts. The part above the base line is called the target bubble area, and contains target bubbles that can stick to each other and to the top of the playing field. Each level begins with a predefined type and number of target bubbles in this area. The part of the playing field below the base line contains a bubble gun with a bullet bubble. The type of bullet bubble is different from that of target bubbles, and is also predefined. For example, in level 22 which is intended to help players learn simple operations, the target bubble type
is lowest terms, and the bullet bubble type is simple operation (see Figure 3.3). The player controls the direction of the bubble gun, indicated by the small dotted line. The player’s goal is to shoot the bullet bubble so that it ends up touching one or more target bubbles whose fractions are equivalent to the one in the bullet bubble. As soon as the bullet bubble collides, if the number of attached matching target bubbles meets the predefined falling threshold, all the matching bubbles drop and disappear. All bubbles hanging below them will drop and disappear as well.

There are two predefined falling thresholds. In most levels, the threshold is one. This means that a fall occurs whenever the bullet bubble hits at least one matching target bubble. In a few levels, the threshold is two which requires the bullet bubble to hit at least two matching target bubbles within a single shot in order for any bubbles to fall. This results in a more challenging game. If a bullet bubble is shot and the falling threshold is not met, the bullet bubble will stick to the others in the target area and become a new target bubble. Its bubble type changes to that of the target bubbles (see Section 3.4.4.2 for more detail). After a bullet bubble is shot, a new bullet bubble appears in the bubble gun. The goal of the game is to remove all the bubbles in the playing field. The game is lost when a target bubble is positioned on the base line.

<table>
<thead>
<tr>
<th>Button</th>
<th>Functionality</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="sound.png" alt="" /></td>
<td>This button brings up a sound control panel.</td>
</tr>
<tr>
<td><img src="quit.png" alt="" /></td>
<td>This button is used to quit the game.</td>
</tr>
<tr>
<td><img src="start.png" alt="" /></td>
<td>This button starts a level (reserved for Phoenix Quest).</td>
</tr>
<tr>
<td><img src="gameover.png" alt="" /></td>
<td>This button is used to quit the current level, and return to the level chooser screen.</td>
</tr>
<tr>
<td><img src="help.png" alt="" /></td>
<td>This button brings up the help screens.</td>
</tr>
</tbody>
</table>

Table 3.3 The Bubble Puzzle buttons.
The game screen’s information area is located on the right side of the playing field, and contains the following information: the level being played, the current score, the current falling threshold, and the next bubble to appear in the bubble gun.

On the right hand side of the game screen, there is a button bar. Table 3.3 shows the list of buttons and their functions.

3.4.3.3 The Game Control

As a result of student feedback in the preliminary evaluation, we changed the bubble gun control method to mouse control instead of keyboard control. The direction of the bubble gun follows the mouse cursor. The player aims by placing the mouse where she or he wants the bullet bubble to go, and clicks to fire. The intent of this modification is to increase the efficiency and precision of game control.

3.4.4 Scaffolding

The levels in Bubble Puzzle are carefully scaffolded so that they gradually increase in cognitive challenge.

3.4.4.1 Order of Levels

The levels are ordered so that the cognitive requirement of fraction knowledge gradually increases, from basic fraction concepts to complex operations. The 50 levels of Bubble Puzzle are divided into 10 groups based on fraction concepts. In each group, the configurations of bubble types are the same. Table 3.4 shows the detailed information of level groups: 2 groups focus on basic fraction concepts, 2 on equivalent fractions, 2 on simple operations, and 4 on complex operations. The different groups
with the same mathematical concept are also ordered in increasing difficulty. For example, there are two groups about equivalent fractions. In the first group, the bullet bubble type is non-lowest terms, and the target bubble type is lowest terms. In this group, the player only needs to reduce the fraction of the bullet bubble to lowest terms and then look for target bubbles with the lowest terms representation. In the second group, the task is harder because the bullet and target types are exchanged. Now the player may have to reduce several target bubble fractions while looking for target bubbles equivalent to the bullet bubble.

Since complex operations are the most difficult mathematical content in Bubble Puzzle, there are more level groups presenting complex operations. The easier levels show an intermediate step in performing the complex operation. This is provided to help students better understand how complex operations are done (see Section 3.4.4.2 for more detail). In the last ten levels of Bubble Puzzle, the bullet type is lowest terms, and the target type is complex operation. This task requires similar understanding and skills to that needed to solve questions in the Poison Puzzle in Phoenix Quest.

<table>
<thead>
<tr>
<th>Mathematical Concept</th>
<th>Level Group</th>
<th>Bullet Type</th>
<th>Target Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic fractions</td>
<td>1-5</td>
<td>Part-Whole</td>
<td>Lowest Terms</td>
</tr>
<tr>
<td></td>
<td>6-10</td>
<td>Lowest Terms</td>
<td>Part-Whole</td>
</tr>
<tr>
<td>Equivalent fractions</td>
<td>11-15</td>
<td>Non-Lowest Terms</td>
<td>Lowest Terms</td>
</tr>
<tr>
<td></td>
<td>16-20</td>
<td>Lowest Terms</td>
<td>Non-Lowest Terms</td>
</tr>
<tr>
<td>Simple operations</td>
<td>21-25</td>
<td>Simple Operation</td>
<td>Lowest Terms</td>
</tr>
<tr>
<td></td>
<td>26-30</td>
<td>Lowest Terms</td>
<td>Simple Operation</td>
</tr>
<tr>
<td>Complex operations</td>
<td>31-35</td>
<td>Complex Operation; shows the step of reduction to a common denominator</td>
<td>Lowest Terms</td>
</tr>
<tr>
<td></td>
<td>36-40</td>
<td>Complex Operation</td>
<td>Lowest Terms</td>
</tr>
<tr>
<td></td>
<td>41-45</td>
<td>Lowest Terms; shows the step of changing to an equivalent simple operation expression</td>
<td>Complex Operation</td>
</tr>
<tr>
<td></td>
<td>45-50</td>
<td>Lowest Terms</td>
<td>Complex Operation</td>
</tr>
</tbody>
</table>

Table 3.4 List of level groups.
3.4.4.2 Visual Transition

In some levels, Bubble Puzzle assists the player with understanding how to change the bullet type fraction into an equivalent target type by showing the transition between types in the bullet bubble immediately after it is fired. For example, level 21 is intended to help students practice simple operations. The target type is lowest terms, and the bullet type is simple operation. When a bullet bubble is fired, before it moves, its fraction representation changes from a simple operation to the equivalent lowest terms fraction. Thus the result of the operation is shown first, and then after a short delay, the bubble moves.

Previous evaluations of Poison Puzzle indicated that the reason students found Poison Puzzle too difficult was because it involved too many complex operations, without providing sufficient opportunities for students to gain the necessary understanding and skills. For example, one of the key steps in complex operations is the reduction of fractions to a common denominator, but many students find this challenging. In Bubble Puzzle, some levels show students this intermediate step of a complex operation to help them gain better understanding. For example, in level 31, the target type is lowest terms, and the bullet type is complex operation. When the player clicks the mouse to shoot a bullet bubble, the complex operation expression in the bullet bubble first changes to the reduced fraction expression with a common denominator. Shortly thereafter, the expression changes to the lowest terms fraction which is the result of the operation. After another short delay, the bullet bubble moves. In later levels, the visual transition hints are omitted, requiring the player to take on more responsibility for finding matching expressions.

3.4.4.3 Color Hint and Falling Threshold

Two additional design features, the color hints and the falling threshold, are used to scaffold each of the level groups shown in Table 3.4. In the easiest level of each group,
Bubble Puzzle uses the bubble color to help students match bubbles. The color hints are gradually withdrawn in the harder levels so that students are required to think deeply about the fraction concepts during the playing. The color hints are provided by coloring equivalent bubbles with the same solid color. When the color hints are not provided, bubbles are multi-colored. Table 3.5 shows examples of each type of coloring.

<table>
<thead>
<tr>
<th>Color Type</th>
<th>Example</th>
<th>Providing Hints (Yes/No)?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid</td>
<td><img src="image" alt="Example" /></td>
<td>Yes</td>
</tr>
<tr>
<td>Multi-</td>
<td><img src="image" alt="Example" /></td>
<td>No</td>
</tr>
</tbody>
</table>

Table 3.5 List of bubble color types.

The remove of the color hints occurs in three sequential steps:

1. Levels with full color hints. Both target bubbles and bullet bubbles are solid-colored, so students can match by color alone.
2. Target color hints. Target bubbles are solid-colored; bullet bubbles are multi-colored. When a bullet bubble is shot, in addition to the changing of its fraction representation type to the target type, its color changes to the appropriate solid color.
3. Levels with no color hints. In these levels, all bubbles are multi-colored. The player must use the fractions to match bubbles.

Raising the falling threshold is used to increase the level of challenge in the game play. A falling threshold of one only requires the player to find one matching target bubble in order to remove some target bubbles with a bullet. A falling threshold of two requires the player to find a contiguous set of two matching bubbles, which is much more difficult and requires deeper thinking about fractions and better planning in advance of each shot.
The five levels in each group are ordered in increasing difficulty by the different combination of color hint and falling threshold. Table 3.6 shows the difficulty setting in each level group.

<table>
<thead>
<tr>
<th>Difficulty Level</th>
<th>Color Hints</th>
<th>Falling Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Full</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Target</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Target</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>None</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>None</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 3.6 List of difficulty setting in each level group.

### 3.4.5 Rewards and Feedback

Most players find scoring an important feature in measuring their achievement. Bubble Puzzle scoring is based on the number of target bubbles removed by the player. Additional points are given when a shot removes more bubbles than the falling threshold. The score accumulates from level to level until the player loses a level. When the player wins a level and replays it, the score still accumulates because we encourage students to try many examples of each level of problem. When the player restarts, the score resets to zero. To get a high score, the student must try as many levels as possible, and must spend considerable time thinking about the underlying fraction concepts to avoid losing any levels.

Sound effects are also used as rewards in Bubble Puzzle. For example, when players shoot down bubbles, positive sound effects are provided. Sound effects also help players understand their progress, and evaluate their choices and decisions.

### 3.4.6 Help Screens

Bubble Puzzle includes help screens for each level that provide more structured information about the concepts in that level. Students are more likely to want to take
advantage of this type of instruction when they are stuck in the middle of a highly motivating challenge than before they have started the challenge [Klawe, 1998b]. Students can access the help screens for a level at any time. Figure 3.5 shows a help screen invoked by the player while playing level 34. This level is intended to help students learn about complex operations, and the help screen shows some examples to guide the student through the mathematical concept. The student's state of play is maintained during access to the help screens, and she or he can return to playing at any time.

![Figure 3.5 Help screen for level 34.](image)

3.4.7 Entertainment Elements

The presence of entertainment elements that are well integrated with the activity is more important than the level of polish and sophistication [Klawe, 1998b]. Bubble Puzzle
includes a number of features which are intended to enhance the level of enjoyment. Some of these are described as follows:

1. The player can bounce the bullet bubble off the sides. This enables players to hit target bubbles that cannot be reached directly. Thus, well-Planed shots can remove many bubbles and achieve high scores.

2. A special bullet bubble occurs at random intervals during the game. This bubble can be filled with any fraction, and hence can be used to remove any accessible target bubble.

3. Colors and patterns are used to make the game attractive. For example, at the beginning of each level, the target bubbles are laid out in a geometric pattern. A different pattern is used for each level.

4. When the mouse cursor moves to the target area, it turns into a crosshair image instead of an arrow to make it more consistent with children’s other gaming experiences.

5. Appropriate sound effects are associated with actions and outcomes. For example, a firing sound for shooting a bubble, a knocking sound for a bullet bubble colliding with a target bubble, and comments like “Great” for winning a level, and “Keep trying” for losing a level.
Chapter 4

Pilot Study

A pilot study was conducted prior to two formal studies. The pilot provided an initial evaluation for both the software and the assessment tools. It played an important role in the game design and the development of the formal studies. The goals of the Pilot Study were as follows:

1. To evaluate the usability of the game in terms of its user interface and stability.
2. To evaluate the effectiveness of the assessment tools.
3. To gather data and experience for designing and running the formal studies.

4.1 Subjects

The Pilot Study was done at Maple Grove Elementary School. Sixteen grade 6 students took part in the study. All students were playing Bubble Puzzle for the first time. All students had obtained parental permission to participate the study.
4.2 Setting and Procedure

The study took place in the computer laboratory of the school; four IBM-compatible laptop computers were used. One pair of students was placed at each computer; at most eight students took part in the study at a time. Each session consisted of four phases: pre-test, game phase, post-test and interview. The duration of each phase was extensive because we wanted to measure the time needed for most students to finish each phase to help us design effective and appropriate settings and procedures for the formal studies. First, the students were asked to complete a pencil-and-paper pre-test designed to gauge their knowledge of fractions. Following completion of the pre-test, the game phase began with a researcher briefly introducing the task and interface of the game. Pairs of students then played the game. It was not possible to let students play all 50 levels in the game, so a number of levels containing different fraction concepts and interface features were selected for the study. During the game phase, researchers observed how students interacted with the game interface, how much difficulty they had in doing various calculations, and how long they took to finish the different levels. After the game phase, the students were asked to complete a post-test which had the same number and format of questions as those on the pre-test. At the end of each session, students were asked to provide us with feedback about the game.

4.3 Results

The results are organized into three parts: usability of the game, test materials and procedures.
4.3.1 Usability of the Game

The following findings regarding the design of the game are based on the student feedback and the observations during the game phase. The resulting changes that were made are also described.

- Children's responses were encouraging. Most indicated that they enjoyed playing the game and liked to learn mathematics from games like Bubble Puzzle.
- Children's responses indicated that they found the hints provided by Bubble Puzzle, including the color hint and intermediate step hint, helpful in understanding the fraction concepts.
- Observations by researchers indicated that the falling threshold was an important factor affecting the level of difficulty. In the levels with a falling threshold of one, students took about 5 minutes to finish a level when they understood the underlying fraction concepts well. In the levels with a falling threshold of two, students took much longer to complete each level. Moreover, they could lose in a level even when they understood the mathematical content well. This supported the design objective to make the activity more game-like.
- Student feedback showed that the game's visual and sound effects for winning or losing a level were not clear enough. We modified the sound effects and added a feedback box at the bottom of the game screen to display messages to players.
- In the levels showing the intermediate step of changing the bullet bubble's fraction expression to one with a common denominator, the students did not respond well to the interface used for this hint. After the click to fire the bullet bubble, the game showed the hint for a few seconds before the bullet bubble moved. The fixed time for showing the hint did not meet all students’ needs. Some students felt it was too long and made the game too slow. Other students wanted it longer. The interface was changed as follows. The first click shows the hint. The second click shoots the bubble. Thus students can see the hint for as long as they want.
• Observations showed that sometimes students had difficulty finishing levels because the bullet bubble fraction was generated too randomly. The formula used to generate the fraction was changed so that the probability that the bullet bubble would be equivalent to a target bubble was increased to 66%.
• Some bubble colors were changed because students indicated that those colors made the fractions too difficult to read.
• The prototype used in the Pilot Study was stable. No crashes occurred during the study. Nevertheless, observations revealed several bugs in the implementation, which were then fixed in the revised version used for the formal studies.

4.3.2 Test Materials

The test materials indicated a promising result with respect to the educational effectiveness of Bubble Puzzle. The mean scores on the pre- and post-test were 62.2% and 75.0% respectively, producing an increase of 12.8%.

1. Circle each item that equals \( \frac{3}{4} \)

\[
\frac{1}{2} \quad \frac{2}{2} \quad \frac{9}{12} \quad \frac{1}{4} + \frac{1}{2} \\
\frac{27}{36} \quad \frac{8}{8} - \frac{1}{4} \quad \frac{14}{16}
\]

Figure 4.1 An example question in the Pilot Study pre- and post-tests.

The questions in the pre-test and post-test used exactly the same format. Each test consisted of four multi-choice questions. Figure 4.1 shows an example. The question combines several fraction concepts including equivalent fractions, simple operations and complex operations. A good understanding of basic fraction concepts is also necessary to do these questions. The results showed that this type of question helped us gauge students' overall fraction knowledge but it was difficult for us to measure students' improvement in understanding finer-grained fraction concepts. More types of
questions were added to the tests used in the formal studies. These will be described in Chapter 5.

4.3.3 Procedures

Observations and student feedback showed that most of the difficulty levels of fraction concepts used in the Pilot Study, including equivalent fractions, simple operations and complex operations, were appropriate. As we had suspected, the levels with basic fraction concepts were too easy. Most students finished these levels very quickly without any difficulty. These results helped us refine the selection of levels and the length of the game phase for the formal studies.

One procedural concern that arose in the Pilot Study was in regard to the timing of the pre-test. The pre- and post-tests were taken by students at the beginning and at the end of each session. Thus it was possible that the improvement made by students in the post-tests might be affected by a learning effect due to the writing of the pre-tests. The timing of the pre-test was changed for the formal studies. Students took the pre-tests a few days before the post-tests in order to minimize any possible learning influence.
Chapter 5

Study Design and Methodology

Two formal studies (Study A and Study B) were conducted with Bubble Puzzle to provide quantitative and qualitative evaluations. The goals of the studies were to:

1. Evaluate Bubble Puzzle’s effectiveness with respect to learning about fractions.
2. Investigate whether Bubble Puzzle met children’s affective needs.
3. Investigate whether the design features of Bubble Puzzle were effective in promoting reflective cognition and better learning.
4. Investigate children’s responses to the features of Bubble Puzzle for entertainment.
5. Investigate whether playing Bubble Puzzle helped students improve their playing of Poison Puzzle.

Multiple research methods were used in the two studies. This chapter describes the design of the research.
5.1 Subjects

The target population for the studies were children in public middle-class Canadian elementary schools. 28 students (14 girls and 14 boys) in grade 6 from a class at University Hill Elementary School took part in Study A, 19 students (9 girls and 10 boys) in grade 5 from a class at False Creek Elementary School took part in Study B. The subjects ranged in age from 10 to 12 years of age, and had received parental permission for their participation in the studies. None of the subjects had played Bubble Puzzle before. Some of the subjects in Study A (6 girls and 6 boys) who had played Poison Puzzle before the study, participated in the investigation of whether playing Bubble Puzzle helped students to play Poison Puzzle.

5.2 Sources of Data

Five sources of data were used in the research: tests, questionnaires, video, direct observations, and interviews. The data collection methods are described as follows:

5.2.1 Tests

There were two types of tests used in the studies: Fraction Knowledge Tests and Poison Puzzle Tests.

5.2.1.1 Fraction Knowledge Tests

The Fraction Knowledge Tests were intended to provide a comparative measure of students’ knowledge about the concepts targeted by Bubble Puzzle, including understanding of some specific finer-grained concepts outlined in Chapter 3. The tests were revised based on results from the Pilot Study. Each test consisted of 4 types of
questions. In addition to the multi-choice questions used in the Pilot Study, questions focused on equivalent fractions, simple operations and complex operations were added to help assess students' understanding of these finer-grained concepts (see Appendix A). Two different versions of the Fraction Knowledge Tests were used in the two studies. Table 5.1 shows the number of questions in the two test versions. The test version used in Study B was both longer and more difficult than that used in Study A.

<table>
<thead>
<tr>
<th>Test Version</th>
<th>Multi-choice question</th>
<th>Equivalent fraction question</th>
<th>Simple operation question</th>
<th>Complex operation question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study A</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Study B</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 5.1 Number of questions in the Fraction Knowledge Tests.

Each test version contained a pre-test and a post-test that were designed to be of the same level of difficulty. The only difference between the pre-test and post-test was the numbers used in the questions.

5.2.1.2 Poison Puzzle Tests

The Poison Puzzle Tests were intended to measure students' ability to play Poison Puzzle as part of the investigation of possible performance improvements. The tests each consisted of 8 questions, 4 easy questions and 4 difficult questions. Figure 5.1 shows two examples, the first is an easy question, and the second is a difficult one. These questions are the same format as those in Poison Puzzle.
Please fill in numbers to make each expression equal.

1. \[\frac{\boxed{1}}{6} + \frac{\boxed{2}}{8} = \frac{11}{12}\]

2. \[\frac{\boxed{3}}{4} + \frac{\boxed{4}}{5} + \frac{\boxed{5}}{6} + \frac{\boxed{6}}{8} + \frac{\boxed{7}}{9} = \frac{24}{45}\]

Figure 5.1 Example questions in the Poison Puzzle Tests.

5.2.1.3 Trial Run of Tests

A trial run of the version of Fraction Knowledge Tests used in Study A and the Poison Puzzle Tests was done in a grade 6 class at the Maple Grove Elementary School to ensure that the pre-tests and post-tests of each version were of the same level of difficulty, and could be completed in a reasonable amount of time.

The mean scores on the Fraction Knowledge pre- and post-test were 83.7% and 81.1%. These results indicated that the two tests were of the same level of difficulty. Most students got high scores in the tests. Nevertheless, a good pre-test score usually does not lead to a large improvement in post-test. This is commonly called the ceiling effect. High pre-test scores show that students had a good understanding of the concepts, and this prevented them from improving as much as those with less understanding of the concepts. The mean scores on the Poison Puzzle pre- and post-test were: 15.5% and 4.7%, respectively. The mean post-test score was 10.8% lower than those in the pre-test. Observations made during students taking the tests indicated that most of them became very frustrated while doing the Poison Puzzle Tests. They spent most of the time thinking during the pre-test, and simply gave up while doing the post-test. With further investigation, we found that only a few students had attempted any of the last four
questions which were the most difficult ones. The results showed that the Poison Puzzle Tests were too long. In the formal studies, the number of difficult questions on the tests was reduced to two from four (see Appendix B).

The tests used in Study B were not evaluated in a trial run as another method was used to balance the difficulty levels of the pre- and post-test. That method is described in Section 5.4.

5.2.2 Questionnaires

Pencil-and-paper questionnaires were completed by subjects during the studies. The purpose of these questionnaires was:

- To investigate children’s attitudes towards motivation provided by Bubble Puzzle (e.g., “I like to learn math from computer games like Bubble Puzzle”, “Bubble Puzzle was fun”).
- To investigate children’s attitudes towards various design features of Bubble Puzzle intended to enhance fraction learning (e.g., “In some levels, you could get hints from the color of the bubbles. Did you find these hints helpful?”).
- To investigate children’s attitudes towards the entertainment elements of Bubble Puzzle (e.g., “I liked the sound effects in Bubble Puzzle”, “I liked the colors and graphics in Bubble Puzzle”).
- To investigate children’s attitudes towards Poison Puzzle (e.g., “Poison Puzzle was fun”, “Poison Puzzle helped me learn about fractions”).
- To investigate children’s attitudes as to whether playing Bubble Puzzle helped them play Poison Puzzle (e.g., “It was easier to play the Poison Puzzle after I had played the Bubble Puzzle”).

For most questions on the questionnaires, responses were rated on a 5-point Likert scale (e.g., strongly agree, agree, neutral, disagree, strongly disagree). There were several versions of questionnaires as shown in Appendix C to meet the slightly different goals of the two studies. For example, in Study A, three versions of questionnaire were used.
Two of them were used after the Poison Puzzle game phase; one of them was used after the Bubble Puzzle game phase.

### 5.2.3 Video

Video was used to record children’s interactions with the game interfaces in order to gather additional data on how children progressed through the game, children’s responses to different design features, the problems they encountered and how they solved these problems. Interviews with a subset of randomly selected children were also videotaped.

### 5.2.4 Direct Observations

Direct observations were made during each session of game playing. Researchers recorded social interactions such as verbal comments of the pairs of players. This provided additional insight, and was expected to be useful for game improvements and further research.

### 5.2.5 Interviews

Two students in each session were randomly selected to be interviewed. Interviews were intended to provide further information on students’ thoughts and feelings about the game. Some questions asked in the interviews were based on how each student answered the questionnaires. The questions included:

1. What do you think of the Bubble Puzzle? Why do you like it?
2. Was Bubble Puzzle more of a “thinking” game, or was it more of a “guessing” game? Why?
3. You say that “Compared to other educational games you have played, you loved Bubble Puzzle.” Why do you say this?
4. Did you use HELP during play? Why?
5. You say that “Bubble Puzzle helped you play Poison Puzzle”, why do you say this?

6. Do you have any suggestions to make the game better?

5.3 Design

An investigation of how playing Bubble Puzzle affected students’ knowledge and skills about fractions was conducted in both Study A and Study B. Students were given a Fraction Knowledge pre-test several days before the Bubble Puzzle study sessions. In the study session, pairs of students played Bubble Puzzle for 40 minutes. Eight levels of Bubble Puzzle, two on equivalent fractions, two on simple operations, and four on complex operations, were selected for the game phase. After the game phase, students were given a Fraction Knowledge post-test. The educational effectiveness of Bubble Puzzle was measured by analysis of students’ performance on the pre- and post-tests.

In Study A, 12 students took part in an additional investigation of whether Bubble Puzzle could help them improve their Poison Puzzle playing. On the first day, students played Poison Puzzle for 30 minutes. This was called the Poison Puzzle pre-game-phase. Their performance was measured by the number of levels passed during the 30-minute phase. On the second day, students did the 40-minute Bubble Puzzle game phase. On the third day, students did another 30-minute Poison Puzzle game phase, the post-game-phase. The 12 students also wrote a Poison Puzzle pre-test on day 1 after the Poison Puzzle pre-game-phase and a Poison Puzzle post-test on day 3 after the Poison Puzzle post-game-phase so that their potential improvement could be evaluated by both their pre- and post-game-phase performance and their Poison Puzzle pre- and post-test scores. The schedule is shown in Table 5.2.
5.4 Setting and Procedure

Consent forms were distributed among all students in each classroom in order to obtain parental permission for their participation in the studies. Study participation was limited to those students who received consent from their parents and who themselves agreed to participate. Four IBM-compatible laptop computers and two video cameras were used in the studies.

<table>
<thead>
<tr>
<th>Day</th>
<th>Number of Subjects</th>
<th>Activity</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Several days before Day 1</td>
<td>28</td>
<td>Fraction Knowledge pre-test</td>
<td>5 mins</td>
</tr>
<tr>
<td>Day 1 Sessions</td>
<td>12</td>
<td>Introduction</td>
<td>5 mins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Poison Puzzle pre-game-phase</td>
<td>30 mins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Poison Puzzle pre-test</td>
<td>10 mins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Poison Puzzle Post-Questionnaire #1</td>
<td>5 mins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Interview</td>
<td>10 mins</td>
</tr>
<tr>
<td>Day 2 Sessions</td>
<td>28</td>
<td>Introduction</td>
<td>5 mins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bubble Puzzle game phase</td>
<td>40 mins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fraction Knowledge post-test</td>
<td>5 mins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bubble Puzzle Post-Questionnaire</td>
<td>5 mins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Interview</td>
<td>5 mins</td>
</tr>
<tr>
<td>Day 3 Sessions</td>
<td>12</td>
<td>Introduction</td>
<td>5 mins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Poison Puzzle post-game-phase</td>
<td>30 mins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Poison Puzzle post-test</td>
<td>10 mins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Poison Puzzle Post-Questionnaire #2</td>
<td>5 mins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Interview</td>
<td>10 mins</td>
</tr>
</tbody>
</table>

Table 5.2 Schedule for sessions in Study A.

Several days before each study, students wrote a Fraction Knowledge pre-test in their classroom. In each study session, students were assigned to work on the computers in pairs because of research indicating that placing two children at each computer can have
a positive effect on performance and learning [Inkpen, Booth, Klawe and Upitis, 1995]. Study A with grade 6 students took three days. Table 5.2 shows the schedule for sessions for each day in Study A. Each session took one hour. There were two sessions in Day 1, four sessions in Day 2, and two sessions in Day 3.

Study B with grade 5 students provided another evaluation of Bubble Puzzle’s educational effectiveness as well as its design features. Study B was conducted in three sessions. The session schedule was similar to that of Day 2 in Study A, with two differences. First, because we did not do a trial run with the version of the Fraction Knowledge Tests used in Study B, we divided the subjects in Study B into two groups of equal size for the pre-test. One group used the first test as its pre-test, and the other group used the second test as its pre-test. Each group used the other test for its post-test. This allowed us to ensure that the pre-test and the post-test were of the same level of difficulty. The second difference was that we selected some questions from the questionnaire used in Study A to form a pre-questionnaire done before the Bubble Puzzle game phase. Questions in the pre-questionnaire were about students’ general attitudes toward learning mathematics and educational software. We had students complete the pre-questionnaire before the game phase to eliminate the influence of playing Bubble Puzzle on their answers.
Chapter 6

Results and Discussion

This chapter discusses the results of our two formal studies. The results are organized into three parts: results on achievement, results on features for enhancing learning, and results on features for motivation and entertainment.

6.1 Results on Achievement

This section presents results on two types of achievement related to Bubble Puzzle: domain learning outcomes and assessment of effectiveness on helping students play Poison Puzzle. Paired samples t-tests were used to compare student performance on pre- and post-tests.

A preliminary analysis was conducted to determine if writing repeated tests had influenced students’ test scores. The data from the trial run (described in Section 5.2.1.3)
were analyzed as a control group. We compared the Fraction Knowledge pre-test and post-test scores. No statistically significant differences were found (t(18) = -1.793, p > .05).

6.1.1 Domain Learning Outcomes

Both Study A and Study B investigated whether Bubble Puzzle could help students improve their understanding of fractions. This section presents students’ fraction learning outcomes.

6.1.1.1 Overall Achievement Outcomes

Score improvements from Fraction Knowledge pre-tests to post-tests were found in both Study A and Study B (see Figure 6.1). The mean score on the pre-test in Study A was high, namely 81.3%, and a 6.6% improvement was found in the post-test; the mean pre-test score in Study B was 36.9%, and there was a 8.6% improvement in the post-test (see Table 6.1 for more detail). There were two reasons that scores in Study B were lower than those in Study A. First, students in Study B were one grade lower than students in Study A. Second, tests used in Study B were designed to be more difficult than those used in Study A in order to avoid the ceiling effect that may have occurred in Study A.

Table 6.2 shows the results of paired samples t-tests for the Fraction Knowledge pre- and post-tests. Significant effects of Bubble Puzzle on overall fraction knowledge achievements were found in both Study A and Study B (Study A: t(27) = 2.83, p < .05; Study B: t(18) = 2.58, p < .05).
Figure 6.1 Mean scores on the Fraction Knowledge Tests (N=47).

<table>
<thead>
<tr>
<th>Study</th>
<th>N</th>
<th>Tests</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study A</td>
<td>28</td>
<td>Pre-test</td>
<td>81.3</td>
<td>17.9</td>
<td>74.7 - 87.9</td>
</tr>
<tr>
<td>Study A</td>
<td>28</td>
<td>Post-test</td>
<td>87.8</td>
<td>11.9</td>
<td>83.4 - 92.2</td>
</tr>
<tr>
<td>Study B</td>
<td>19</td>
<td>Pre-test</td>
<td>38.1</td>
<td>13.8</td>
<td>31.9 - 44.3</td>
</tr>
<tr>
<td>Study B</td>
<td>19</td>
<td>Post-test</td>
<td>46.7</td>
<td>19.4</td>
<td>38.0 - 55.4</td>
</tr>
</tbody>
</table>

Table 6.1 Descriptive statistics for the Fraction Knowledge Tests

<table>
<thead>
<tr>
<th>Paired Samples (post-test - pre-test)</th>
<th>N</th>
<th>Paired Differences</th>
<th>t</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Std. Deviation</td>
<td>Std. Error Mean</td>
</tr>
<tr>
<td>Study A</td>
<td>28</td>
<td>6.55</td>
<td>12.25</td>
<td>2.31</td>
</tr>
<tr>
<td>Study B</td>
<td>19</td>
<td>8.60</td>
<td>14.54</td>
<td>3.34</td>
</tr>
</tbody>
</table>

Table 6.2 Paired samples t-tests for the overall scores of Fraction Knowledge Tests.

6.1.1.2 Finer-Grained Achievement Outcomes

In this section, test scores were analyzed according to the three finer-grained concepts in the tests: equivalent fractions, simple operations and complex operations. Pre- and post-test scores of each concept were compared to investigate the learning effectiveness of Bubble Puzzle with respect to each concept.
**Equivalent Fraction**

Figure 6.2 indicates that in Study A the mean score on equivalent fraction questions in pre-test was very high, namely 90.7%. These students showed good understanding of this concept, and there was no mean score improvement in the post-test. In Study B, the mean score on equivalent fraction questions in the pre-test was 45.4%, and a 14.0% improvement was found in the post-test.

![Figure 6.2 Mean scores on equivalent fraction questions (N=47).](image)

A statistically significant improvement was found in Study B ($t(18) = 2.46$, $p < .05$). No significant difference was found in Study A ($t(27) = .24$, $p > .05$). (See Table 6.3)

<table>
<thead>
<tr>
<th>Paired Samples (post-test - pre-test)</th>
<th>N</th>
<th>Paired Differences</th>
<th>t</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Std. Deviation</td>
<td>Std. Error Mean</td>
</tr>
<tr>
<td>Study A</td>
<td>28</td>
<td>.71</td>
<td>15.62</td>
<td>2.95</td>
</tr>
<tr>
<td>Study B</td>
<td>19</td>
<td>14.04</td>
<td>24.85</td>
<td>5.70</td>
</tr>
</tbody>
</table>

Table 6.3 Paired samples t-tests for equivalent fraction question scores.
Simple Operation

The mean scores on simple operations questions in the pre-tests were quite high in both Study A and Study B, namely 83.2% and 77.0%, respectively (see Figure 6.3). One reason was that our marking scheme of this type of question considered both reduced and unreduced answers as correct answers since we were only measuring students' understanding of simple operations, and not equivalent fractions. This type of question was relatively easy for students since the operation only involved addition or subtraction of two numerators. Most students showed good mastery of simple operations in the pre-tests, and improvements on post-tests were small. In Study A, the post-test mean score increased by 6.6%, and no significant difference was found (t(27) = 1.49, p > .05). In Study B, the post-test mean score decreased by 6.0%, and no significant difference was found either (t(18) = -.67, p > .05). (See Table 6.4).

![Figure 6.3 Mean scores on simple operation questions (N=47).](image)

<table>
<thead>
<tr>
<th>Paired Samples (post-test – pre-tests)</th>
<th>N</th>
<th>Paired Differences</th>
<th>t</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Std. Deviation</td>
<td>Std. Error Mean</td>
</tr>
<tr>
<td>Study A</td>
<td>28</td>
<td>6.63</td>
<td>23.48</td>
<td>4.44</td>
</tr>
<tr>
<td>Study B</td>
<td>19</td>
<td>-6.02</td>
<td>39.07</td>
<td>8.96</td>
</tr>
</tbody>
</table>

Table 6.4 Paired samples t-tests for simple operation question scores.
**Complex Operation**

The results in Figure 6.4 show that larger improvements in the scores of complex operation questions were found in both studies, namely 17.9% and 12.0%. The pre-test mean scores indicated that most of the students did not have a good understanding of this concept. This was especially true for students in Study B whose mean score was only 2.0%. These students had been introduced to complex operations one week before the study, and their teacher indicated that most of the students had not yet grasped the concept.

![Figure 6.4 Mean scores on complex operation questions (N=47).](image)

Significant improvements between pre- and post-test scores on complex operation questions were found in both studies (Study A: t(27) = 4.32, p < .05; Study B: t(18) = 3.09, p < .05. See Table 6.5).

<table>
<thead>
<tr>
<th>Paired Samples (post-test – pre-tests)</th>
<th>N</th>
<th>Paired Differences</th>
<th>t</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Std. Deviation</td>
<td>Std. Error Mean</td>
</tr>
<tr>
<td>Study A</td>
<td>28</td>
<td>17.86</td>
<td>21.87</td>
<td>4.13</td>
</tr>
<tr>
<td>Study B</td>
<td>19</td>
<td>11.96</td>
<td>16.89</td>
<td>3.87</td>
</tr>
</tbody>
</table>

Table 6.5 Paired samples t-tests for complex operation question scores.
6.1.1.3 Summary and Discussion

The results showed that Bubble Puzzle helped students improve their understanding of the target fraction knowledge. It especially helped students gain a better understanding of the concepts that they did not understand well. Complex operations were the most difficult of the three finer-grained concepts. The pre-test scores for this concept were the lowest. After 40 minutes of Bubble Puzzle play, significant improvements were found in both studies. The pre-test scores on equivalent fraction questions showed that the grade 6 students had a better understanding of this concept than the grade 5 students. The grade 6 students had high pre-test scores, and no significant improvement on post-test scores, while the grade 5 students significantly increased their post-test scores. For the simple operation concept, most students showed good understanding of this concept in the pre-tests, and no significant difference was found in the post-tests of either study.

The results from the questionnaires and interviews were consistent with those from the Fraction Knowledge Tests. Table 6.6 displays the distribution of children’s perceptions about Bubble Puzzle’ effectiveness for learning mathematics. The distributions of children’s responses in the two studies were similar. Most students stated that they gained a better understanding about fractions after playing Bubble Puzzle.

<table>
<thead>
<tr>
<th></th>
<th>Strongly agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study A</td>
<td>10.7%</td>
<td>53.6%</td>
<td>17.9%</td>
<td>10.7%</td>
<td>7.1%</td>
</tr>
<tr>
<td>Study B</td>
<td>15.8%</td>
<td>52.6%</td>
<td>21.0%</td>
<td>5.3%</td>
<td>5.3%</td>
</tr>
<tr>
<td>Mean</td>
<td>13.2%</td>
<td>53.1%</td>
<td>19.5%</td>
<td>8.0%</td>
<td>6.2%</td>
</tr>
</tbody>
</table>

Table 6.6 The distribution of children’s responses to the question: Bubble Puzzle helped me learn about fractions (N=47).

From direct observations we found that when a level involving a new concept began, students usually played relatively slowly. They made more mistakes if they did not understand the concept well. They paid more attention to the color hints and intermediate step hints provided by the game. Usually after a period of learning and
practice, they seemed to understand the underlying concept. They then continued to play quickly with fewer mistakes. In harder levels without any hints, students again spent time practicing.

**6.1.2 Effect on Poison Puzzle Playing**

Two types of achievement data were used to measure whether Bubble Puzzle helped students play Poison Puzzle: Poison Puzzle Tests and the number of levels passed in the Poison Puzzle game phases. Figure 6.5 shows the mean results. Table 6.7 displays the results of the statistical analysis. The students who took part in the assessment of Bubble Puzzle’s effectiveness on improving Poison Puzzle playing in Study A had had experience playing Poison Puzzle before the study. Their Poison Puzzle pre-test mean scores (64.0%) were much better than those of the control group in the trial run. There was an 11.1% improvement in the post-test, but no significant difference was found ($t(11) = 1.27$, $p > .05$). The mean percentages of the selected levels in Poison Puzzle passed by students in the pre- and post-game-phases were 36.1% and 77.8%. The increase of 41.7% after playing Bubble Puzzle was found to be significant ($t(11) = 4.86$, $p < .05$).

![Figure 6.5 Mean scores on the Poison Puzzle Tests and the number of levels passed in the Poison Puzzle game phases (N=12).](image-url)
<table>
<thead>
<tr>
<th>Paired Samples (post- – pre-)</th>
<th>N</th>
<th>Paired Differences</th>
<th>t</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Std. Deviation</td>
<td>Std. Error Mean</td>
</tr>
<tr>
<td>Poison Puzzle Test</td>
<td>12</td>
<td>11.11</td>
<td>30.43</td>
<td>8.78</td>
</tr>
<tr>
<td>Number of levels passed in Poison Puzzle game phase</td>
<td>12</td>
<td>2.50</td>
<td>1.78</td>
<td>.51</td>
</tr>
</tbody>
</table>

Table 6.7 Paired samples t-tests for the Poison Puzzle Tests and the number of levels passed in the Poison Puzzle game phases.

The results of questionnaires and interviews indicated that most students thought Poison Puzzle was of above average difficulty. 75% of the students felt it was easier to play Poison Puzzle after they had played Bubble Puzzle. 83% of the students indicated that questions in the last 10 levels of Bubble Puzzle helped them think about questions in Poison Puzzle. In our observations, we found that in the Poison Puzzle pre-game-phases, students only finished at most half of the selected levels. In the post-game-phases, many students completed all the selected levels. Some of them even finished before the end of the session.

### 6.2 Results on Features for Enhancing Learning

In this section, we examine children’s responses to the design features for enhancing learning. Table 6.8 displays the mean results of two related questions in the questionnaires. Responses were rated on a 5-point Likert scale (e.g., A. strongly agree; B. agree; C. neutral; D. disagree; E. strongly disagree) in which “A” responses on the scale were assigned a value of 5, and “E” responses were assigned a value of 1.

Most students indicated that the hints helped them learn the underlying fraction concepts while playing the game, especially when playing a new level with a concept that was not well understood. The gradual removal of hints made them think more. Table 6.9 shows the distribution regarding children’s responses to a question about
which setting for color hints helped them learn the most. 13.3% of the students thought full color hints made them learn most; more than half the students (55.8%) thought that levels with no color hints made them learn the most. In these levels they had to think hard for each calculation.

<table>
<thead>
<tr>
<th>Question</th>
<th>Study A</th>
<th>Study B</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>In some levels, you could get hints from the color of the bubbles. The color hints were helpful.</td>
<td>4.1</td>
<td>4.3</td>
<td>4.2</td>
</tr>
<tr>
<td>In some levels, you could watch the step of reduction of a fraction to a common denominator. The intermediate step hints were helpful.</td>
<td>3.8</td>
<td>3.3</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Table 6.8 Children’s responses regarding the design features for enhancing learning (N=47).

<table>
<thead>
<tr>
<th>Color hints setting of levels</th>
<th>Study A</th>
<th>Study B</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full color hints</td>
<td>10.7%</td>
<td>15.8%</td>
<td>13.3%</td>
</tr>
<tr>
<td>Target color hints</td>
<td>7.1%</td>
<td>0.0%</td>
<td>3.6%</td>
</tr>
<tr>
<td>No color hints</td>
<td>53.6%</td>
<td>57.9%</td>
<td>55.8%</td>
</tr>
<tr>
<td>All types</td>
<td>28.6%</td>
<td>26.3%</td>
<td>27.3%</td>
</tr>
</tbody>
</table>

Table 6.9 The distribution of children’s responses to the question about which setting for color hints helped them learn the most (N=47).

Observations showed that 10% of the students used the help screens during their playing. The two main reasons for using the help screens identified in the interviews were: 1) “I wanted to find some help”; 2) “I wanted to see what was in it”. As to the reason for not using it, most students indicated that they were paying too much attention to the game playing and didn’t think about using it.

6.3 Results on Features for Motivation and Entertainment

In terms of Bubble Puzzle’s affective impact, children’s responses showed strong positive reactions towards the game and its design features. Table 6.10 displays the means of responses to questions which were used to investigate Bubble Puzzle’s features aimed at motivation and entertainment. The scoring scheme was the same as
that in Table 6.8. The strongly positive responses were assigned a value of 5, and the strongly negative responses were assigned a value of 1. The results suggest that Bubble Puzzle met children’s affective needs as most of the means were above 4.0 out of 5.0. A few students who reported having little interest in mathematics in the questionnaires, also indicated they liked to learn mathematics from computer games like Bubble Puzzle. The fun features were showed to be attractive to players. Children were particularly fond of the special bubble which they could fill with any fraction they wanted to, as well as the colors and graphics in Bubble Puzzle.

<table>
<thead>
<tr>
<th>Question</th>
<th>Study A</th>
<th>Study B</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>I like to learn math from computer games like Bubble Puzzle.</td>
<td>3.8</td>
<td>4.2</td>
<td>4.0</td>
</tr>
<tr>
<td>Compared to other educational games you played, how much did you like playing Bubble Puzzle?</td>
<td>4.1</td>
<td>4.1</td>
<td>4.1</td>
</tr>
<tr>
<td>The game was fun.</td>
<td>3.7</td>
<td>4.3</td>
<td>4.0</td>
</tr>
<tr>
<td>In some levels, the minimum number of falling bubbles is three. These levels made the puzzle more fun.</td>
<td>3.3</td>
<td>3.1</td>
<td>3.2</td>
</tr>
<tr>
<td>I liked the colors and graphics in Bubble Puzzle.</td>
<td>4.1</td>
<td>3.8</td>
<td>4.0</td>
</tr>
<tr>
<td>I liked the special bubble that I could fill with any fraction I wanted to.</td>
<td>4.4</td>
<td>4.4</td>
<td>4.4</td>
</tr>
<tr>
<td>I liked the sound effects in Bubble Puzzle.</td>
<td>3.7</td>
<td>3.6</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Table 6.10 Children’s responses to questions about the design features for motivation and entertainment (N=47).

Direct observations and interviews that were made during the study provided more results to support the findings from questionnaires. Children showed a high level of interest while playing the game. There were lots of interactions within each pair of students, as well as between pairs of students. Both girls and boys wanted to control the mouse. Mouse control usually switched several times in each pair during play. “I like Bubble Puzzle! It was so fun!”, were the most common comments in the interviews. And children showed a strong desire to play the game again. The results suggest that Bubble Puzzle provided a motivating learning environment for children, and that the entertainment features were conducive to children’s enjoyment of the learning activity.
Chapter 7

Conclusions and Future Research

7.1 Summary

Bubble Puzzle, a game-based interactive learning environment was developed. The goal of Bubble Puzzle was to assist elementary school children in understanding fractions. A game activity was designed to support the exploration of a number of target fraction concepts and to provide an enjoyable environment for children. Techniques such as visual feedback and scaffolding were used in the design to promote reflective cognition so that children would develop a deeper understanding of the mathematical concepts. A number of entertainment features were added to the game to make it a more enjoyable environment.

Two studies with 47 elementary school children were conducted with the following goals: to evaluate Bubble Puzzle’s effectiveness with respect to learning about fractions;
to investigate whether the design features were effective in promoting reflective cognition and better learning; to investigate whether Bubble Puzzle met children’s affective needs; to obtain children’s responses to the entertainment design features; and to investigate whether playing Bubble Puzzle helped students improve their playing of Poison Puzzle – another mathematical game involving more advanced fraction knowledge and skills.

Children’s test scores and their perceptions of their own learning suggest that Bubble Puzzle helped them improve their understanding of the underlying fraction concepts. It especially helped students gain a better understanding of the concepts that they did not understand well. For example, students’ pre-test scores indicated that most of them did not have a good mastery of complex operations. In the post-tests, children’s score improvements on complex operations were the greatest among the three finer-grained concepts. Significant improvements were found in both studies. Children’s responses to the design features for enhancing learning were positive. Most students indicated that these features helped them gain a better understanding of the underlying concepts.

The results suggest that Bubble Puzzle provided a motivating environment for children to explore the underlying mathematical concepts. The entertainment features of Bubble Puzzle matched children’s interests and were conducive to their enjoyment of the learning activity.

The results indicated that playing Bubble Puzzle helped children improve their playing of Poison Puzzle. Children gained fraction knowledge and skills required by Poison Puzzle during their Bubble Puzzle playing.

7.2 Limitations of the Research

Some limitations of the research are as follows:
1. The studies were conducted in small rooms rather than in more realistic school settings such as classrooms. Students knew that they were taking part in a research study, and therefore, might have changed their behavior.

2. Students played selected levels of the game for forty minutes before being evaluated in the post-tests. Extending the playing period to let students try all levels of the game might produce stronger results.

3. Students played the game in pairs. It was difficult to determine how much each student contributed or whether one student dominated the play in some pairs.

4. The participants were grade 5 and grade 6 students, so the results may not generalize to students in other grades.

5. The studies did not compare playing Bubble Puzzle with other traditional learning exercises such as textbook exercises. More insight would be gained if control groups were included.

7.3 Future Research

The current results suggest some directions for future research:

1. Research is needed to investigate whether the positive effect of a specific design feature is replicable in different domains, with learners of different ages, and over longer periods of instruction.

2. Research is needed to develop guidelines and principles on how to select suitable game activities that support a high degree of interactivity for learning different mathematical concepts.

3. Research is needed to develop guidelines and principles on how to design effective navigational structures and sequencing of activities for different domains.

4. Research is needed to develop guidelines and principles on how to design different styles of interfaces suitable for different types of learners.
5. Research is needed to investigate how to precisely assess users' understanding of the domain in order to provide more targeted and adaptive feedback.

6. Research is needed to investigate what types of entertainment elements promote children's motivation without distracting them from the exploration of the mathematical concepts.

7. Research is needed to develop guidelines and principles on how to design effective instructional components, and how to motivate children to use them more often.

Developing game-based interactive mathematics learning environments for children is a still relatively new idea and a challenging task. Sound research in a wide range of related areas is needed in order to create more and more usable learning environments.
Bibliography


62


Appendix A

Fraction Knowledge Tests

A.1 Study A - Pre-Test

1. Circle each item that equals \( \frac{1}{2} \)

   \[
   \frac{1}{1} + \frac{0}{1} \quad \frac{6}{12} \quad \frac{1}{3} + \frac{1}{6} \\
   \frac{11}{22} \quad \frac{3}{4} - \frac{1}{4} \quad \frac{2}{3}
   \]

2. Circle each item that equals \( \frac{7}{10} \)

   \[
   \frac{17}{20} \quad \frac{1}{5} + \frac{1}{2} \quad \frac{3}{5} + \frac{4}{5} \\
   \frac{14}{5} \quad \frac{3}{4} - \frac{1}{20} \quad \frac{28}{40}
   \]

Circle T for true, or circle F for false.

1. \( \frac{3}{4} = \frac{6}{8} \)  T  F  Don't know

2. \( \frac{3}{5} = \frac{9}{15} \)  T  F  Don't know

3. \( \frac{2}{3} = \frac{4}{7} \)  T  F  Don't know

4. \( \frac{3}{8} = \frac{6}{16} \)  T  F  Don't know
Fill in the answer:

1. \( \frac{2}{5} - \frac{1}{5} = \) ________ Don't know

2. \( \frac{3}{4} - \frac{1}{4} = \) ________ Don't know

3. \( \frac{2}{7} + \frac{5}{7} = \) ________ Don't know

4. \( \frac{2}{6} - \frac{1}{6} = \) ________ Don't know

Fill in the answer:

1. \( \frac{1}{6} + \frac{2}{5} = \) ________ Don't know

2. \( \frac{1}{5} - \frac{1}{10} = \) ________ Don't know

3. \( \frac{1}{3} + \frac{2}{4} = \) ________ Don't know

4. \( \frac{1}{7} + \frac{2}{5} = \) ________ Don't know
A.2 Study A - Post-Test

1. Circle each item that equals $\frac{3}{4}$

- $\frac{1}{2} + \frac{2}{2}$
- $\frac{9}{12}$
- $\frac{1}{4} + \frac{1}{2}$
- $\frac{6}{8}$
- $\frac{4}{4} - \frac{1}{4}$
- $\frac{4}{5}$

2. Circle each item that equals $\frac{5}{12}$

- $\frac{15}{36}$
- $\frac{1}{6} + \frac{1}{4}$
- $\frac{3}{6} + \frac{2}{6}$
- $\frac{10}{6}$
- $\frac{2}{3} - \frac{1}{4}$
- $\frac{15}{22}$

Circle T for true, or circle F for false.

1. $\frac{2}{4} = \frac{6}{8}$  
   T  F  Don't know

2. $\frac{3}{5} = \frac{6}{15}$  
   T  F  Don't know

3. $\frac{1}{5} = \frac{4}{7}$  
   T  F  Don't know

4. $\frac{3}{8} = \frac{6}{16}$  
   T  F  Don't know
Fill in the answer:

1. \( \frac{3}{4} - \frac{1}{4} = \) Don't know

2. \( \frac{3}{5} - \frac{1}{5} = \) Don't know

3. \( \frac{2}{8} + \frac{3}{8} = \) Don't know

4. \( \frac{2}{6} - \frac{1}{6} = \) Don't know

Fill in the answer:

1. \( \frac{1}{2} + \frac{1}{3} = \) Don't know

2. \( \frac{1}{5} - \frac{1}{10} = \) Don't know

3. \( \frac{1}{4} + \frac{1}{6} = \) Don't know

4. \( \frac{1}{6} + \frac{1}{3} = \) Don't know
A.3 Study B - Test 1

1. Circle each item that equals \( \frac{1}{2} \)

\[
\begin{align*}
\frac{1}{1} + \frac{0}{1} & \quad \frac{6}{12} & \quad \frac{1}{3} + \frac{1}{6} \\
\frac{11}{22} & \quad \frac{9}{12} - \frac{1}{4} & \quad \frac{2}{3}
\end{align*}
\]

2. Circle each item that equals \( \frac{7}{10} \)

\[
\begin{align*}
\frac{17}{20} & \quad \frac{1}{5} + \frac{1}{2} & \quad \frac{3}{4} + \frac{4}{6} \\
\frac{14}{5} & \quad \frac{5}{6} - \frac{4}{30} & \quad \frac{28}{40}
\end{align*}
\]

Circle T for true, or circle F for false.

1. \( \frac{3}{4} = \frac{4}{8} \)  \( T \quad F \quad \) Don’t know

2. \( \frac{5}{20} = \frac{4}{15} \)  \( T \quad F \quad \) Don’t know

3. \( \frac{12}{9} = \frac{20}{15} \)  \( T \quad F \quad \) Don’t know

4. \( \frac{2}{3} = \frac{18}{24} \)  \( T \quad F \quad \) Don’t know

5. \( \frac{3}{8} = \frac{21}{56} \)  \( T \quad F \quad \) Don’t know

6. \( \frac{5}{9} = \frac{40}{71} \)  \( T \quad F \quad \) Don’t know
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>( \frac{3}{5} - \frac{1}{5} = )</td>
</tr>
<tr>
<td>2.</td>
<td>( \frac{5}{14} - \frac{3}{14} = )</td>
</tr>
<tr>
<td>3.</td>
<td>( \frac{19}{36} - \frac{13}{36} = )</td>
</tr>
<tr>
<td>4.</td>
<td>( \frac{2}{7} + \frac{4}{7} = )</td>
</tr>
<tr>
<td>5.</td>
<td>( \frac{16}{22} - \frac{9}{22} = )</td>
</tr>
<tr>
<td>6.</td>
<td>( \frac{10}{28} - \frac{3}{28} = )</td>
</tr>
</tbody>
</table>

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>( \frac{1}{12} + \frac{1}{4} = )</td>
</tr>
<tr>
<td>2.</td>
<td>( \frac{7}{35} - \frac{1}{7} = )</td>
</tr>
<tr>
<td>3.</td>
<td>( \frac{3}{4} - \frac{2}{5} = )</td>
</tr>
<tr>
<td>4.</td>
<td>( \frac{1}{3} + \frac{1}{8} = )</td>
</tr>
<tr>
<td>5.</td>
<td>( \frac{2}{16} + \frac{2}{7} = )</td>
</tr>
<tr>
<td>6.</td>
<td>( \frac{1}{9} + \frac{2}{10} = )</td>
</tr>
</tbody>
</table>
A.4 Study B - Test 2

1. Circle each item that equals \( \frac{3}{4} \)

\[
\begin{align*}
\frac{1}{2} + \frac{2}{2} & \quad \frac{9}{12} & \quad \frac{1}{4} + \frac{1}{2} \\
\frac{27}{36} & \quad \frac{4}{4} - \frac{4}{16} & \quad \frac{4}{5}
\end{align*}
\]

2. Circle each item that equals \( \frac{5}{9} \)

\[
\begin{align*}
\frac{15}{19} & \quad \frac{1}{3} + \frac{2}{9} & \quad \frac{3}{6} + \frac{2}{3} \\
\frac{15}{3} & \quad \frac{5}{6} - \frac{5}{18} & \quad \frac{20}{36}
\end{align*}
\]

Circle T for true, or circle F for false.

1. \( \frac{2}{4} = \frac{6}{8} \)  
   T  F  Don’t know

2. \( \frac{6}{20} = \frac{5}{15} \)  
   T  F  Don’t know

3. \( \frac{20}{8} = \frac{15}{6} \)  
   T  F  Don’t know

4. \( \frac{3}{5} = \frac{30}{45} \)  
   T  F  Don’t know

5. \( \frac{2}{9} = \frac{14}{63} \)  
   T  F  Don’t know

6. \( \frac{7}{8} = \frac{47}{56} \)  
   T  F  Don’t know

74
Fill in the answer:

1. $\frac{3}{4} - \frac{1}{4} =$ Don't know
2. $\frac{4}{15} - \frac{1}{15} =$ Don't know
3. $\frac{18}{35} - \frac{11}{35} =$ Don't know
4. $\frac{2}{8} + \frac{3}{8} =$ Don't know
5. $\frac{12}{26} - \frac{7}{26} =$ Don't know
6. $\frac{9}{32} - \frac{1}{32} =$ Don't know

Fill in the answer:

1. $\frac{1}{15} + \frac{1}{3} =$ Don't know
2. $\frac{6}{30} - \frac{1}{6} =$ Don't know
3. $\frac{4}{5} - \frac{1}{4} =$ Don't know
4. $\frac{1}{4} + \frac{1}{9} =$ Don't know
5. $\frac{3}{18} + \frac{2}{7} =$ Don't know
6. $\frac{1}{8} + \frac{3}{18} =$ Don't know
Appendix B

Poison Puzzle Tests

B.1 Pre-Test

Please fill in numbers to make each expression equal. For example:

\[ \frac{1}{6} + \frac{1}{9} = \frac{5}{18} \]

\[ \frac{0}{4} + \frac{0}{5} + \frac{2}{6} + \frac{2}{8} + \frac{0}{9} = \frac{28}{48} \]

1. \[ \frac{\square}{5} + \frac{\square}{8} = \frac{36}{40} \]
   Don't know

2. \[ \frac{\square}{5} + \frac{\square}{6} = \frac{28}{30} \]
   Don't know

3. \[ \frac{\square}{4} + \frac{\square}{9} = \frac{13}{18} \]
   Don't know

4. \[ \frac{\square}{6} + \frac{\square}{8} = \frac{11}{12} \]
   Don't know

5. \[ \frac{\square}{4} + \frac{\square}{5} + \frac{\square}{6} + \frac{\square}{8} + \frac{\square}{9} = \frac{24}{45} \]
   Don't know

6. \[ \frac{\square}{4} + \frac{\square}{5} + \frac{\square}{6} + \frac{\square}{8} + \frac{\square}{9} = \frac{33}{54} \]
   Don't know
B.2 Post-Test

Please fill in numbers to make each expression equal. For example:

\[
\frac{1}{6} + \frac{1}{9} = \frac{5}{18}
\]

\[
\frac{0}{4} + \frac{0}{5} + \frac{2}{6} + \frac{2}{8} + \frac{0}{9} = \frac{28}{48}
\]

1. \[
\frac{\square}{4} + \frac{\square}{6} = \frac{10}{24}
\]
   Don't know

2. \[
\frac{\square}{6} + \frac{\square}{9} = \frac{14}{36}
\]
   Don't know

3. \[
\frac{\square}{6} + \frac{\square}{5} = \frac{11}{15}
\]
   Don't know

4. \[
\frac{\square}{5} + \frac{\square}{4} = \frac{7}{10}
\]
   Don't know

5. \[
\frac{\square}{4} + \frac{\square}{5} + \frac{\square}{6} + \frac{\square}{8} + \frac{\square}{9} = \frac{36}{40}
\]
   Don't know

6. \[
\frac{\square}{4} + \frac{\square}{5} + \frac{\square}{6} + \frac{\square}{8} + \frac{\square}{9} = \frac{22}{24}
\]
   Don't know

77
Appendix C

Questionnaires

C.1 Study A - Bubble Puzzle Post-Questionnaire

PLEASE CIRCLE THE ANSWER THAT BEST SUITS YOU.

1. I like math.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree

2. I often play computer games.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree

   If yes, what type of games: _____________________________________________

3. I like to learn math from computer games like BubblePuzzle.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree

4. Compared to other educational games you played, how much did you like playing BubblePuzzle?
   A) loved it
   B) liked it
   C) so-so
   D) disliked it
   E) hated it
5. How challenging was the game for you?
   A) very challenging
   B) challenging
   C) so-so
   D) easy
   E) very easy

6. The game was fun.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree

7. The game helped me learn about fractions.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree

8. I liked the colors and graphics in Bubble Puzzle.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree

9. In some easy levels, you could get hints from the color of the bubbles. The color hints were helpful.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree

10. Which levels did you like the most?
    A) color hints available for all bubbles
    B) color hints available for only target bubbles
    C) no color hints
    D) I liked all levels
11. Which levels made you learn the most?

A) color hints available for all bubbles  
B) color hints available for only target bubbles  
C) no color hints  
D) All the same

12. In some levels, you can watch the bubble change the denominators of the two fractions into a common denominator.

This happens right before the bubble is shot. The intermediate step hints were helpful.

A) strongly agree  
B) agree  
C) neutral  
D) disagree  
E) strongly disagree

13. In levels specified in last question, the changing of the two fractions to a common denominator helped me think about common multiples.

A) strongly agree  
B) agree  
C) neutral  
D) disagree  
E) strongly disagree

14. I liked the special bubble that I could fill with any fraction I wanted to.

A) strongly agree  
B) agree  
C) neutral  
D) disagree  
E) strongly disagree

15. In some levels, the minimum number of falling bubbles is two. These levels made the puzzle more fun.

A) strongly agree  
B) agree  
C) neutral  
D) disagree  
E) strongly disagree
16. I liked the sound effects in BubblePuzzle.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree

17. How important is it for you to have sound effects in a game?
   A) very important
   B) important
   C) so-so
   D) not important
   E) not at all important

18. How important is it for you to get a good score in a game?
   A) very important
   B) important
   C) so-so
   D) not important
   E) not at all important
C.2 Study A – Poison Puzzle Post-Questionnaire #1

PLEASE CIRCLE THE ANSWER THAT BEST SUITS YOU.

1. I like to learn math from computer games like Poison Puzzle.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree

2. Have you played this puzzle before?
   A) Yes
   B) No

   If yes, how many times?

3. The game was fun.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree

4. The game helped me learn about fractions.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree

5. How difficult was the game for you?
   A) very difficult
   B) difficult
   C) so-so
   D) not difficult
   E) not at all difficult

82
6. How challenging was the game for you?

   A) very challenging
   B) challenging
   C) so-so
   D) not challenging
   E) not at all challenging

7. How many levels did you pass today?
C.3 Study A – Poison Puzzle Post-Questionnaire #2

PLEASE CIRCLE THE ANSWER THAT BEST SUITS YOU.

1. It was easier to play the Poison Puzzle after I had played the Bubble Puzzle.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree

2. Questions in the last 10 levels of Bubble Puzzle helped me think about questions in Poison Puzzle.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree

3. I found playing the Bubble Puzzle easier than playing the Poison Puzzle.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree

4. How many levels did you pass today?

84
C.4 Study B – Bubble Puzzle Pre-Questionnaire

PLEASE CIRCLE THE ANSWER THAT BEST SUITS YOU.

1. I like math.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree

2. I often play computer games.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree

If yes, what type of games: _____________________________

3. I like to learn math from computer games.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree
C.5 Study B – Bubble Puzzle Post-Questionnaire

PLEASE CIRCLE THE ANSWER THAT BEST SUITS YOU.

1. I like to learn math from computer games like Bubble Puzzle.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree

2. Compared to other educational games you played, how much did you like playing Bubble Puzzle?
   A) loved it
   B) liked it
   C) so-so
   D) disliked it
   E) hated it

3. How challenging was the game for you?
   A) very challenging
   B) challenging
   C) so-so
   D) easy
   E) very easy

4. The game was fun.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree

5. The game helped me learn about fractions.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree
6. I liked the colors and graphics in Bubble Puzzle.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree

19. In some easy levels, you could get hints from the color of the bubbles. The color hints were helpful.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree

7. Which levels did you like the most?
   A) color hints available for all bubbles
   B) color hints available for only target bubbles
   C) no color hints
   D) I liked all levels

8. Which levels made you learn the most?
   A) color hints available for all bubbles
   B) color hints available for only target bubbles
   C) no color hints
   D) All the same

9. In some levels, you can watch the bubble change the denominators of the two fractions into a common denominator.
   This happens right before the bubble is shot. The intermediate step hints were helpful.
   A) strongly agree
   B) agree
   C) neutral
   D) disagree
   E) strongly disagree
10. In levels specified in last question, the changing of the two fractions to a common denominator helped me think about common multiples.

A) strongly agree  
B) agree  
C) neutral  
D) disagree  
E) strongly disagree

11. I liked the special bubble that I could fill with any fraction I wanted to.

A) strongly agree  
B) agree  
C) neutral  
D) disagree  
E) strongly disagree

12. In some levels, the minimum number of falling bubbles is two. These levels made the puzzle more fun.

A) strongly agree  
B) agree  
C) neutral  
D) disagree  
D) strongly disagree

13. I liked the sound effects in BubblePuzzle.

A) strongly agree  
B) agree  
C) neutral  
D) disagree  
E) strongly disagree

14. How important is it for you to have sound effects in a game?

A) very important  
B) important  
C) so-so  
D) not important  
E) not at all important

88
15. How important is it for you to get a good score in a game?

A) very important
B) important
C) so-so
D) not important
E) not at all important