Game-based Improvement of Learning Fractions Using iOS Mobile Devices

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ABSTRACT

Education plays a pivotal role in shaping the future of any nation. Researchers, pedagogists, and teachers all over the world are constantly working towards improving the process of teaching at all levels of education in order to help impart knowledge in a more effective way. One of the most fundamental branches of education is mathematics. Unless a strong foundation is laid in childhood, it becomes difficult for adults to apply mathematics to their daily lives. Mathematics is such a field that it is integrated in most of our activities. Fractions, a mathematics topic, pose significant challenges for middle school students Although the students generally understand proper fractions (i.e., the numerator is smaller than the denominator), they find it very difficult to learn improper fractions (i.e., the numerator is greater than the denominator). One cannot do away with parts of mathematics curriculum, just because the concept is hard to grasp.

The solution is to come up with alternative methods to teach these concepts, such that they are easier to understand and more fun to learn. This thesis describes a digital game-based solution for teaching fractions to middle school students using iOS mobile devices, i.e., iPad, iPhone, and iPod Touch. We developed a universal iOS game, called Candy Factory, which runs on all iOS mobile devices. The game assigns the student the role of the owner of a Candy Factory and tasks the student to manufacture a candy bar to match the kind and size of a customer order from a whole candy bar that is retrieved from the warehouse. The game is created to teach fractions based on the concept of partitioning and iterating. The student performs various activities such as partitioning, iterating, and measuring to produce the candy bar to satisfy the customer requirements. The game consists of three levels, which help the student progress smoothly from easier problems to more difficult ones. The Candy Factory game, not only helps students learn the fundamentals of fractions, but also makes the learning process enjoyable.

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LIST OF ACRONYMS

2D	Two Dimensional
2G	Second Generation
3D	Three Dimensional
3G	Third Generation
4G	Fourth Generation
API	Application Programming Interface
BSP	Board Support Package
CDC	Connected Device Configuration
CLDC	Connected Limited Device Configuration
CLR	Common Language Runtime
CSS	Cascading Style Sheets
GB	Gigabytes
HP	Hewlett-Packard
HTML	HyperText Markup Language
IDE	Integrated Development Environment
IEEE	Institute of Electrical and Electronics Engineers
iOS	Apple’s mobile Operating System
Java ME	Java platform Micro Edition
JDE	Java Development Environment
K-12	Kindergarten (4-6 years old) through grade 12 (16-19 years old)
OpenGL ES	Open Graphics Library Embedded Systems
OOP	Object-Oriented Paradigm
OS	Operating System
QNX	Quick Unix
SDK	Software Development Kit
SGL	Skia Graphics Engine
SSL	Secure Sockets Layer
SVGT	Scalable Vector Graphics - Tiny
TCP/IP	Transmission Control Protocol/Internet Protocol
UI	User Interface
webOS	Hewlett-Packard's mobile operating system
Wi-Fi	Wireless Fidelity
WP	Windows Phone
XAML	Extensible Application Markup Language
XNA	Xbox/DirectX New generation Architecture

CHAPTER 1: INTRODUCTION

"If we teach today, as we taught yesterday, we will be robbing our children of tomorrow."

-John Dewey.

The importance of education has been growing manifold through the years as its importance has been increasing in the modern society. From ancient times it has been noticed that practical learning has been more beneficial to the students, e.g., sticks and stones, the abacus, etc., helping reinforce concepts better than books. Researchers and pedagogists have been trying to exploit the advances in technology so that they can amalgamate with traditional teaching techniques and develop methodologies which emphasize "learning by doing" or "active learning" to help students learn better. This is especially helpful to teach math concepts, which most students find difficult in grasping. It has been observed that the latest advent of technology fascinating the children of today is the array of digital games. Research has proven that if we embed mathematical concepts in these digital games, and considering the level of engagement children play these games with, it can significantly help them learn these mathematical concepts better in a more enjoyable manner.

1.1 Fractions

A test conducted in 2001 showed that pediatricians, nurses, and pharmacist were tested for errors resulting from the calculation of drug doses for neonatal intensive care infants. Of the calculation errors identified, 38.5% of pediatricians' errors, 56% of nurses' errors, and 1% of pharmacists' errors would have resulted in administration of 10 times the prescribed dose [Grillo et al. 2001]. These resounding results led to deeper analysis that weak foundations in fraction concepts in children, have resulted in struggling adults when it comes to calculations involving fractions [Lipkus et al. 2001; Reyna and Brainerd 2007].

Fraction is formally defined as the ratio of two whole numbers, or to put it simply, one whole number divided by another whole number. Depending on the values of these numbers, it can be either *proper* (numerator is smaller than denominator) or *improper* (numerator is bigger than denominator) fraction. Although it has a simple definition, teaching this abstract concept to the students poses significant challenges. The fractions learning process consists of five interrelated sub-constructs namely part-whole, ratio, operator, quotient, and measure, which prove to contribute to the complexity of teaching and learning fractions. Various studies have laid foundation for the well-documented fact that learning fractions is one of the most complicated tasks for primary children [Boulet 1998; Davis et al. 1993]. Hasemann [1981] derived possible hypothesis regarding the difficulties fractions pose for children. The primary reason is that fractions are not used in daily life regularly. Other reasons include (a) the written notation of fractions is relatively complicated, (b) ordering fractions on a number line is exceedingly difficult; and (c) there are many rules associated with the procedures of fractions, and these rules are more complex than those of natural numbers.

Gould et al. [2006] conducted research to delve deeper into the mistakes children tend to make while representing fractions. The age group of children considered was between 12 and 13 years old. They assigned children the task of illustrating fractions one half, one sixth and one third on circle diagrams. They observed that children could depict parts of a set but not parts of a whole. To elucidate this further, for example, if they were to represent one-sixth, they would mark one item out of six items. But when given a circle, they would fumble. They would divide the circle into eight parts, shade 6 of them and then represent one of them as one-sixth. However, one half fraction was an exception, most students were successful in representing one-half on the circle.

Some other studies conducted in Singapore [MMEAG 2001] uncovered that though children may sometimes arrive at the correct results, the method they use turns out to be incorrect.

Studies show that teachers tried various methods to teach fractions to children such as real world applications, using manipulatives or building on prior knowledge. However, the main strategies remain to be direct teaching methodology or by rote or the traditional paper-pencil technique. They generally don't try to go beyond the conventional methodologies to encourage the children to think laterally or collaboratively, which might help them understand the concepts better. The design of instruction is very crucial to help children understand fractions better.

Naiser et al. [2004] went one step ahead and analyzed learning fractions from a psychological perspective. This analysis involves looking at the developmental and psychological units, which define rational numbers into two perspectives. One is global which looks at proportional evaluation and second is local which looks at splitting and doubling.

The explanation of part whole of a fraction is where a number like 1/5 indicates that a whole has been separated into five equal parts and one of those parts is being considered. Splitting, another fractional scheme, consists of simultaneous composition of partitioning and iterating.

Mostly the middle school students use the part whole concept to deal with all fractions concepts. On the other hand, Norton and Wilkins [2009] indicate that the part-whole concept provides no meaning for improper fractions because part-whole fractions are taken out of the whole (taking nine parts out of seven makes no sense). Norton [2009] and Steffe [2004] indicate that robust conceptions of improper fractions depend on the development of splitting operation.

Teachers and researchers are continually working towards making fractions more understandable for children and laying a stronger foundation for them [Bruce and Ross 2007]. Many possible solutions have been discussed in literature. One of them being integrating computer technology and using it as an aide in teaching mathematics.

1.2 Computer Technology in Learning

Mathematics learning is ultimately about refinement and abstractions of ideas and concepts, and mathematics teaching is the process of facilitating this refinement and abstractions. The abstraction here means that starting with concrete examples and moving on to how the techniques for these concrete examples can be applied on a more general basis. Thus basically this abstraction process works best with manipulatives and collaborative discussion and reflection with peers and teachers [English and Halford 1995].

Zbiek [1998] suggests that the use of computers could help improve mathematical modeling ability and increase the levels of abstraction or conceptualization of higher-level concepts. This can be done by providing students with interesting learning activities, which can be explored in tandem with regular school teaching.

Lemke [1998] believes that learning by integrating both text and visual-graphical interpretation helps students look at information from different viewpoints and offers greater potential in formulating concepts and relationships. Computers serve as effective learning aides because they have the potential to offer information both textually and graphically.

When these alternative-learning techniques came into picture, teachers feared that they might replace traditional teaching methodologies, which they strongly believed in. But then as Luke et al. [2000] point out, newer technologies can never completely replace old ones. In fact they aid the traditional methodologies, to help students learn the concepts better.

Here is an analogy for how computers can be used like real life concrete tools to help learning. For example, to teach parts of fractions, generally teachers would use papers and fold them into equal parts. Similarly, rectangles and parts can be drawn on a computer screen and students can be asked to shade parts of the whole to represent fractions as depicted in the Figure 1.

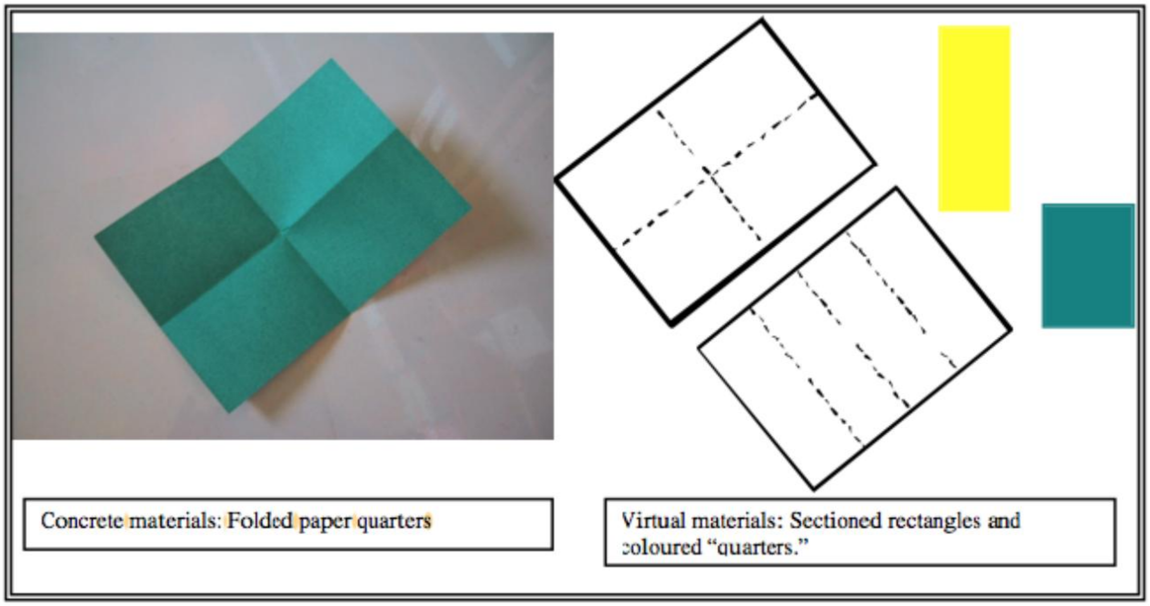

Figure 1. Real (Concrete) and Virtual Materials for Common Fractions [Proctor et al. 2002].
(Used under fair use guidelines, 2011)

Proctor et al. [2002], conducted a case study on a student from a year 7 class, approximately 12-13 year old, who had difficulty grasping the concept of fractions and kept making repeated mistakes. Computer-based and non-computer-based activities involving fractions were combined which helped the student clear his misconceptions and understand the concept better. Collaborative learning and moving back and forth between concrete and virtual tools seemed to be the factor, which helped the student succeed in his attempt to understand fractions. This case study goes to show the efficacy of computer technology as an aide to learning for students and has motivated researchers and pedagogists to explore good computer-based mathematical manipulatives and interactive learning tools for students in elementary and middle school levels to help them bridge the gap between abstraction and concrete mathematics.

One of the most engaging ways to make learning interesting and at the same time useful for students is to inculcate learning in the fun activities they do. In the current age of digitalization, studies showed that digital games were the activity children spend most of their free time on. Hence utilizing digital game-based learning for fractions seems to be an effective approach. Before we venture deeper into this topic, we present a brief overview of digital gaming, its benefits, and how they can be exploited to enhance learning.

1.3 Digital Gaming

The digital gaming was introduced in the 1970's with Pong [The International Arcade Museum 1995] and has been growing exponentially since then and it is forecasted that video game industry to reach $70 billion by 2015 [DFC Intelligence 2010]. The interest that today's children have towards video games is quite what we hope they have the same level of interest for school. They are competitive, inquisitive, motivated, persistent and seek out new information when it comes to playing video games. The approximate time spent by an average American on video games, by the time they turn 21 is around 10,000 hours [Prensky 2003]. Researchers and teachers try to inculcate this same enthusiasm towards school and learning. Hence the ideology for combining learning with digital games was formulated.

What may seem to the untrained eye, as flying airplanes, driving fast cars, being theme park operators or warriors on a battlefield, to the trained eye there is a lot more to it. Gaming indirectly teaches you things like inculcating information from various sources as rapidly as possible and help in decision making. It also enhances collaboration in multiplayer games and overcoming obstacles to understand complex systems through experimentation. Multiple studies have consistently found that games promote learning and/or reduce instructional time across multiple disciplines and ages [Szczurek 1982].

The study by Kebritchi et al. [2010] explains the other benefits of using computer tools for learning mathematics. The computer games are effective in helping children understand complex mathematical concepts because they are more action oriented than explanation oriented. Moreover, the points earned in a game or the level reached tend to offer personal motivation to the children, encouraging them to perform better. These games accommodate children with various learning styles and levels of mastery and teach them interactive decision making corresponding to the context.

1.4 Related Work

1.4.1 Computer Gaming for Math

In this section, we provide brief overviews of some of the computer games created to improve the effectiveness of learning some mathematical concepts.

1.4.1.1 Astra EAGLE

There have been various studies on how to use computer gaming to teach mathematics to children. ASTRA EAGLE [Ke 2008], a series of web based mathematical computer games was developed by the Center for Advanced Technologies based on the Pennsylvania System of School Assessment (PSSA). These games were developed using Macromedia Flash and targeted 4^{th} and 5^{th} grade students.

Astra EAGLE consisted of 8 different mathematical games, which targeted variety of math skills ranging from solving simple equations, comparing whole numbers, mapping x and y coordinates and measurements. For example the goal of treasure hunt, one of the Astra EAGLE games, was to dig for treasure by locating it using x and y coordinates. Another game called Cashier required students to do math calculations of money. Each of these games kept tab of students scores and employed progressive difficulty levels that is as they progressed through the game the problem got harder. Experience with the Astra EAGLE game reveals that computer games tend to increase the positive attitude in students for learning mathematics.

1.4.1.2 DimensionM

Another instructional mathematical game named DimensionM [Kebritchi et al. 2010] was used in public high schools to study their effect on mathematical ability of students. It was noticed that the students who played DimensionM regularly performed better in district-wide math benchmark exams in comparison to students who did not.

DimensionM focuses on pre-algebra and pre-algebra I and has single layer and multiplayer games involving players in completing missions related to mathematical problems. For example, in swarm, a team based DimensionM game, students work together, computing against other teams from their class by gaining points whenever they solve mathematics problems correctly. It also has other games like meltdown which focuses on the speed skill in solving mathematical problems and obstacle course strategic team based game which involves five major stages with mathematics related obstacles.

Figure 2 illustrates the conceptual framework and the relationships among the variables and adapted theories in this study. This framework consists of three main stages of learning input, game learning process, and learning outcome.

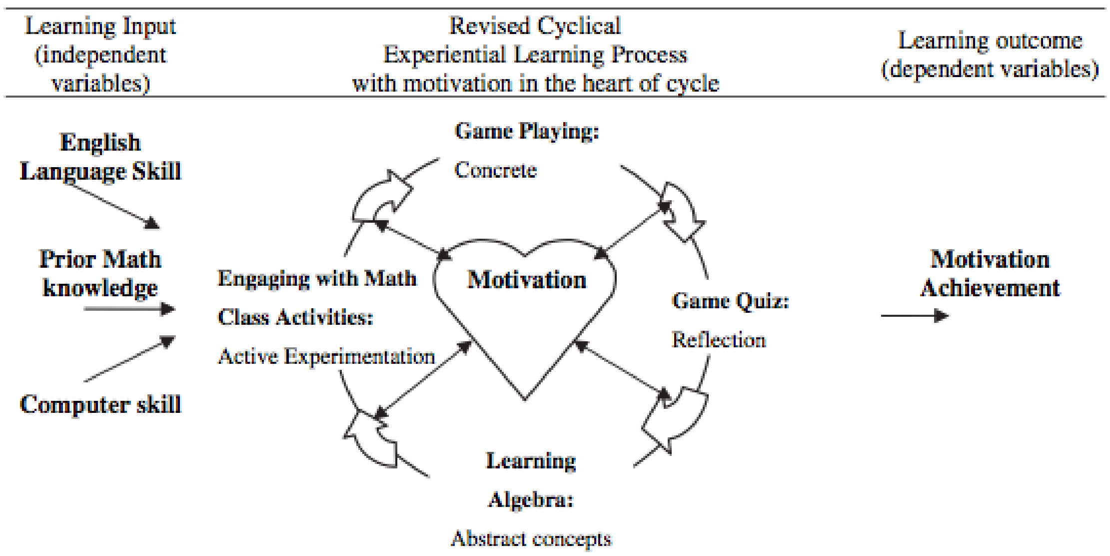

Figure 2. Conceptual framework and the relationships between the variables and adapted theories [Kebritchi et al. 2010]. (Used under fair use guidelines, 2011)

The benefit of instructional mathematical games was analyzed from the perspective of both students and teachers. The students found these games to be effective because they combined both learning and fun and offered mathematics in an exploratory manner. The teachers seemed to find these games very useful because they were experiential in nature and increased the time spent on learning mathematics by students.

1.4.2 Virtual Manipulatives for Learning Fractions

Virtual manipulatives are replicas of physical manipulatives depicted as dynamic objects using web-based visual representation. Generally, to teach concepts of fractions, teachers and instructors use physical manipulatives. However, these might offer several limitations. A good way of overcoming them is to use virtual manipulatives instead. Reimer and Moyer [2005] explore the effect of using virtual manipulatives computer applets for teaching a fraction unit for third graders.

The virtual manipulatives help students connect the dynamic visual images with abstract symbols, a feature not offered while learning via physical manipulatives. Feedbacks collected from several students showed that they found virtual manipulative methods easier to use than the paper and pencil method. It prevented the common error patterns observed in fraction addition and encouraged students to notice mathematical relationships.

This virtual manipulatives gives students the control and ability to manipulate objects and discover mathematical principles using exploration. As students used the technology further, it was observed that they enjoyed learning more and demonstrated improvement in their mathematical concepts. Virtual manipulative technologies are viewed as a promising tool to help students learn mathematical concepts visually [Suh et al. 2005; Proctor et al. 2002].

1.4.3 Fraction-Based Digital Games

Many digital games have been developed to facilitate learning fractions. Some of them are described below in no particular order.

1.4.3.1 Joyce

Joyce [Feng et al. 2005] is an online computer game which encourages players to combine numbers in different ways with arithmetic operators. It has been implemented in such a way that the players can either compete against another real-life player or the computer itself. This collaborative nature of Joyce encourages student to learn concepts better via teamwork and competition. This game mechanism encourages students to learn fractions in a dynamic grouping environment. It has been targeted for 5th graders and divided into five levels of difficulties. Figure 3 shows the user interface. It contains several parts like public area, private area, generating area, dicing area, quiz item area, exchange area, and answering area.

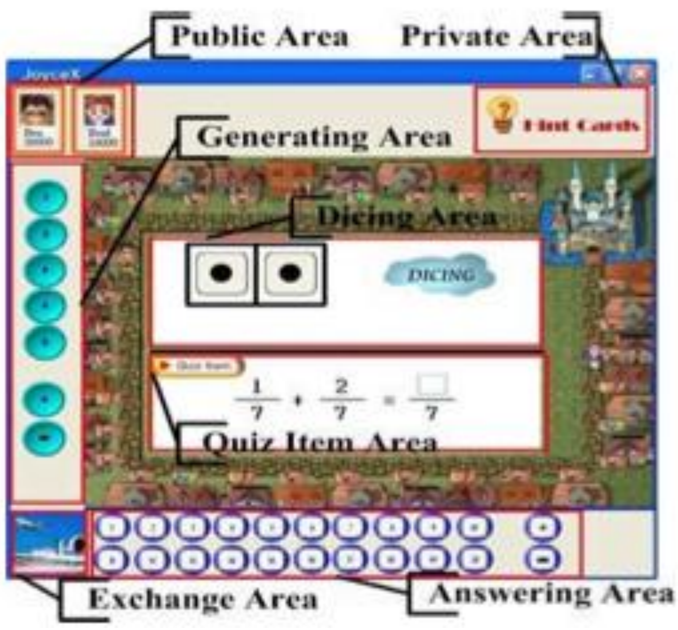

Figure 3. Client interface of Joyce [Feng et al. 2005]. (Used under fair use guidelines, 2011)

This study points out that though collaborative learning is useful, the competitive factors that this game induces cannot be ignored. As part of future improvement for Joyce, it would be beneficial to maintain individual data logs of each student's learning process, which could be further analyzed to build students' specific models and detect the cognitive aspects.

1.4.3.2 Cognitive Tools

Another educational tool, Cognitive Tools (CT) [Kong 2008] uses exploratory process to teach students the procedural knowledge of adding and subtracting fractions. These fractions can have like and unlike denominators.

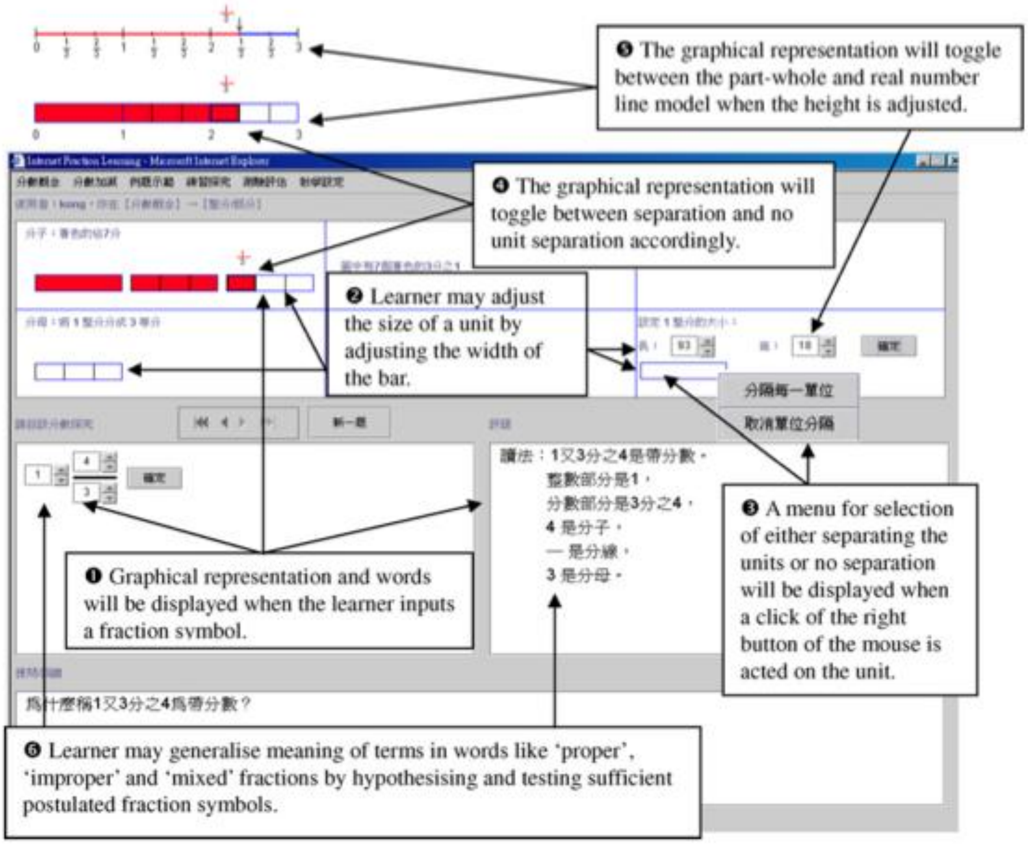

Figure 4. Graphical partitioning model as graphical presentation tool linking fraction symbols with meaning [Kong 2008]. (Used under fair use guidelines, 2011)

The CT is a web-based learning tool. It uses graphical representation of fractions to utilize students' initial knowledge of the part-whole concept of fractions. Figure 4 shows the graphical representation tool linking fraction symbols with meanings. The graphical model links the familiar linear shaped rectangular bar with fractions. Teachers found this tool effective in tutoring students and likewise the students found this tool stimulating as well. This tool was used in pre-test-post-test control group empirical study and has been discovered to have potential for the development, which could enhance collaborative learning of fraction concepts among students in classroom.

1.4.3.3 CLIPS

CLIPS [Bruce and Ross 2007]**,** a technology-based learning resource was developed by a team of teachers, researchers, and educational software developers to provide the sequencing and scaffolding, which are difficult for teachers to provide. CLIPS consists of 5 sets of fractional tasks:

- Representing simple fractions
- Forming and naming equivalent fractions
- Comparing simple fractions

- Forming equivalent fractions by splitting or merging parts
- Representing improper fractions as mixed numbers

Each of the above tasks consists of introductory instructions, interactive actions, consolidation activities and quizzes. CLIPS tries to use examples like visual representations of pizza or nutrition bar. It presents students with real life situations like rectangular nutrition bar is to be shared among two or three friends and asks them to solve problems based on that. Before the game begins, CLIPS provides an introduction, which emphasizes on the components of fractions like numerator or denominator in terms of the objects described earlier.

CLIPS also has a number of additional sets of activities. It tries to provide immediate feedback to the students, and in case they are incorrect it gives them explanation to help them rectify their mistakes. In addition, CLIPS enables students to do consolidating learning using the "show what you know" feature. The success of CLIPS lies in the fact that it amalgamates the three important contexts namely the technological contexts, teaching contexts, and student contexts.

1.4.3.4 Fraction Brick Game

The topic of comparing fractions sizes, an important aspect of the fractions curriculum in New Zealand has been explored by the Fraction Brick Game [Lee 2008]. The game builds a story line of a boy who has to build a staircase made of fractions bricks in order to reach home.

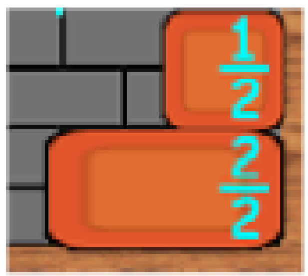

Figure 5. Visible long bricks [Lee 2008]. (Used under fair use guidelines, 2011)

In this game, the fraction bricks are used to represent different sizes of fractions. There are two types of fraction bricks as shown in Figure 5. The tall brick orders fractions from smallest to largest and the long brick orders fractions from largest to smallest.

The fraction brick game tries to explore fractions using three game themes ranging from concrete to abstract. To elucidate further, there might be (a) *visible bricks*, which represent sizes of fractions that can be seen, (b) *broken bricks*, which can be divided into parts to represent visible fractions, and (c) *hidden bricks*, which are labeled with only symbols of fractions. The game was found to increase in difficulty, as the game progress requires more complex strategies. It was tested with 8th grade students and feedback was taken on how the game can be further improved to better improve the process of learning fractions.

1.4.3.5 UFractions

UFractions [Turtiainen et al. 2009] is one of the latest story based fraction games that was developed for mobile devices and was tested in 2009 on 8th grades students in 5 South African schools and on students and teachers of the University of Pretoria, South Africa.

This study had multiple objectives. Apart from exploratory fraction learning it also explored the phenomena of mobile gaming in developing countries. This game also tried to build a story line like some of the games described above. The story in UFraction revolves around mother leopard and her cub Senatala, which the students tend to identify themselves with.

UFractions uses the Myst platform, which provides a mobile learning environment for different contexts. This platform facilitates development of multiuser, networked mobile applications on Java enabled mobile devices.

The goal of the game is to solve problems using Hungarian Mathematical manipulatives, which are collections of twelve colored rods, each having a different color and length. Figure 6 depicts an example problem using the rods.

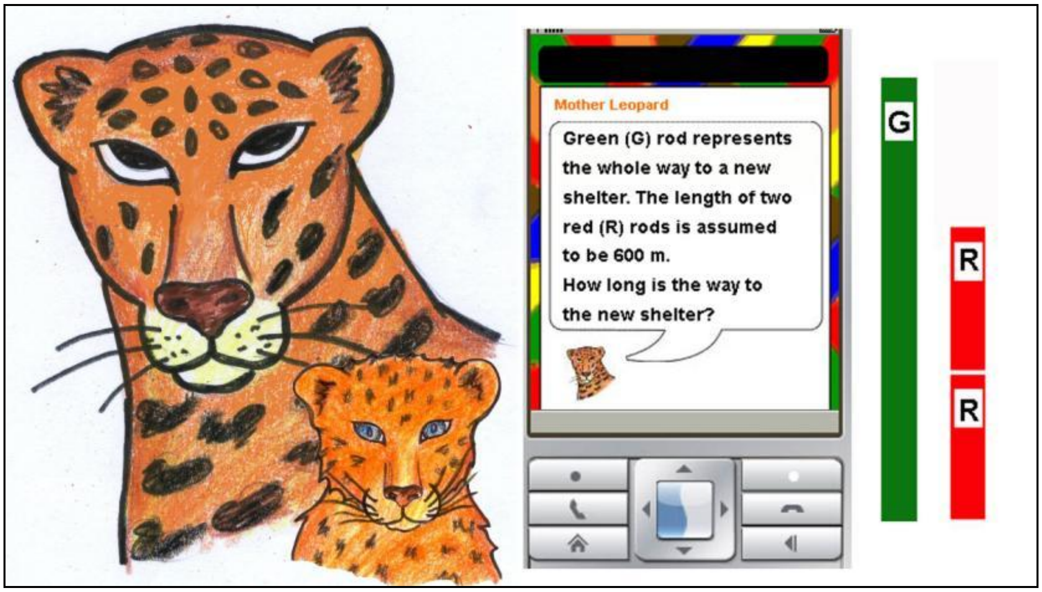

Figure 6. Mother Leopard, her cub Senatla, example of mathematical problem and the use of rods [Turtiainen et al. 2009]. (Used under fair use guidelines, 2011)

The game begins with four introductory problems, which guides the player on how to use the rods. After that, different enigmas are introduced as fraction problems in terms of activities like feeding the cub 0-16 weeks, lessons to hunt: 4-12 months, etc. Every problem is provided with a context-sensitive hint that could be asked to the mother leopard after an incorrect answer. The game also provides scores of teams and guest book entries.

Qualitative and quantitative strategies are employed to assess the effect of the game on students. Almost all participants found the game exciting and actively discussed the math problems with their friends to arrive at the correct solutions. One of the few drawbacks of UFractions is that it has been tested only on Nokia 80 and N95 mobile devices.

1.4.4 Fraction Games on the Internet

The online or web-based games are generally intended to provide animated, curriculum-based content that engages students, supports educators, and improves student achievement. Most of the available games are supported by educators, teacher communities or freelance game designers [Utah State University 1999].

The games available on the Internet are used in different ways, to teach right from the basics to complex subject matters. Some of these games provide content that is aligned to academic standards [BrainPOP 1999]. Most of the games are fully compatible with interactive whiteboards, learner response systems, projectors, Macs, and PCs. No downloading, installation or special hardware is required.

One of the games, Calculation Nation allows students not only to challenge themselves and explore mathematical concepts, but also allows them to choose opponents from any part of the world and challenge them. This competitive yet collaborative spirit adds an edge of excitement to the game [NCTM 2011]. This effort is a part of the NCTM Illuminations project, which offers Standards-based resources to help improve learning and teaching of mathematical concepts to students.

1.4.5 Fraction Games on the App Store

In the Apple App Store, more than 25 iPhone and 7 iPad apps focus on teaching/learning fractions. These apps are designed to perform various fraction operations like addition, subtraction, multiplication and division [Apple 2011].

Around 20 iPhone and 6 iPad apps focus on the basics of fractions using the pie approach to teach the basic concept of fractions, proper fractions and improper fractions, mixed numbers and converting mixed numbers into the improper fractions [Apple 2011].

1.5 Statement of the Problem

Fractions is an important concept that needs to be learned and mastered during the middle school to achieve better understanding of algebraic topics in later years. Currently, most middle school students are aware of partitioning and iterating operations, but only a few thoroughly understand the splitting operations. Most students’ knowledge of fractions is limited to part-whole concepts.

Apart from the regular curriculum taught in schools, for middle school students, extra support is needed to develop understanding of splitting operations in fractions, where the splitting operation is defined as the simultaneous combination of partitioning and iterating process. Any positive improvements in teaching fraction concepts will benefit millions of middle school students.

1.6 Statement of Objectives

The objectives of the work described herein consist of the following: (a) develop a digital game called Candy Factory to teach fractions to middle school students, (b) enable students to more effectively learn the concept of splitting operations for fractions, (c) engage students in sequential applications of partitioning and iterating operations in a goal-directed activity involving fractions, and (d) provide the game on all iOS mobile devices, i.e., iPad, iPhone, and iPod Touch.

1.7 Overview of Thesis

This thesis is organized as follows: Chapter 2 gives an overview of mobile software engineering platforms. Chapter 3 describes the Candy Factory game developed. Chapter 4 presents a self-evaluation of the developed game. Finally, Chapter 5 states concluding remarks, contributions, and future work.

CHAPTER 2: MOBILE SOFTWARE ENGINEERING PLATFORMS

An overview of mobile software engineering platforms is provided in Table 1 [Balci 2011]. Each platform is briefly described below.

2.1 Apple iOS

iOS stands for Apple's mobile Operating System (OS). Initially it was created for just iPhone environment, but later it was also used for iPod Touch, iPad, and 2nd generation Apple TV. The initial iOS version was released on June 29, 2009 and the latest version iOS 4.3 was released on March 9, 2011 [Broughall 2010]. iOS controls the mobile device hardware components and provides the OS software to run iOS software applications.

iOS and Mac OS X use a common heritage. iOS is a Unix operating system by its nature. At the highest level, iOS acts as an intermediary between the underlying hardware and the applications that run. Applications communicate with the hardware through a set of well-defined system interfaces. The provided abstraction enables the applications to run without being effected by hardware changes [Apple 2010a]. Figure 7 depicts the iOS layers of abstraction for application software development.

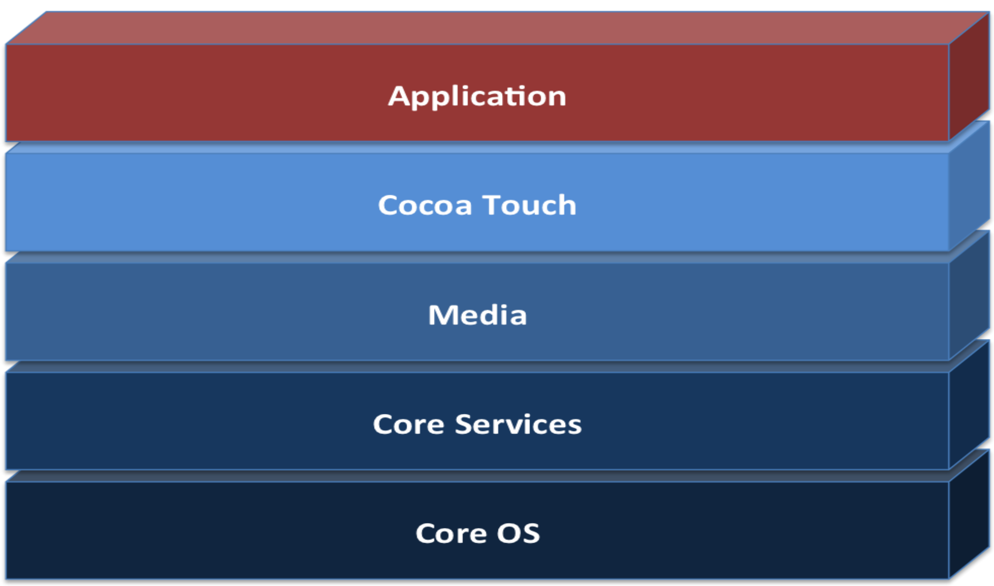

Figure 7. iOS layers of abstraction [Apple 2010b].

The Core OS and Core Services layers contain the fundamental interfaces for iOS such as accessing files, low-level data types, and network services. The Core Services layer contains both the Foundation as well as the Core foundation, which provide abstractions for common data types like strings and collections.

The Media Layer contains the fundamental technologies used to support 2D and 3D drawing, audio, and video. In addition, this layer enables some technologies such as OpenGL ES, Quartz and Core Audio and Core Animation. Its purpose is to provide graphical services to Cocoa touch layer.

Table 1. Mobile Software Engineering Platforms

Platform	*Mobile Devices*	*Operating System*	*Programming Language*	*Software Development Kit (SDK) / Integrated Development Environment (IDE)*	*Developer Website*	*Application Distribution*
Apple iOS	• iPhone • iPod touch • iPad	iOS - derived from Mac OS X, which is a Unix OS	Objective C 2.0	iOS SDK including: • Xcode IDE with iOS Simulator • Dashcode, Instruments, Quartz Composer	• iOS Dev Center	• Apple App Store
Google Android	Smartphones, Tablets, E-readers, and others.	Android OS (Mobile OS based on Linux kernel)	Java	• Android SDK • Motorola Dev Studio for Android • Sony Ericsson Android Developer Tools	• Android Developers • HTC Developer Center • Motorola Developer Network • Sony Ericsson Developer World	• Android Market • Android App Marketplace
Microsoft Windows Phone	Smartphones, Tablets, E-readers, and others.	Windows Phone 7 OS	C#, C++, VB.NET	• Microsoft Visual Studio • Windows Phone Emulator • Silverlight • XNA Game Studio • Microsoft Expression Blend • .NET Framework	• Windows Phone Developer	• Windows Phone Marketplace • Windows Mobile App Marketplace
RIM BlackBerry	Smartphones and Tablets	BlackBerry OS, QNX OS	Java	• BlackBerry Java Application Development • BlackBerry Theme Studio • BlackBerry Smartphone Simulators • BlackBerry Web Development	• BlackBerry Developer Zone	• BlackBerry App World
HP Palm	Smartphones and Tablets	HP webOS (Mobile OS based on Linux kernel)	C, C++, Java	• HP webOS Platform SDK/PDK	• HP Palm Developer Center	• HP Palm App Marketplace • HP Palm Apps
Nokia Symbian	Smartphones	Symbian OS	C++, Java	• Nokia Symbian SDK • Sony Ericsson Symbian Foundation	• Nokia App Developers • Sony Ericsson Developer World	• Symbian OS App Marketplace
Java platform Micro Edition (Java ME)	Smartphones by • BlackBerry • LG • Motorola • Nokia • Samsung • Sony Ericsson • etc.	Mobile OS based on Linux kernel	Java	• BlackBerry JDE Plug-in for Eclipse • Eclipse Mobile Tools for Java • LG SDK for Java ME • Motorola SDK for Java ME • Nokia IDEs: NetBeans and Eclipse • Samsung SDK for Java ME • Sony Ericsson SDK for Java ME • Oracle SDK for Java ME	• BlackBerry Developer Zone • Eclipse Mobile Tools for Java • LG Mobile Developer Network • Motorola Developer Network • Nokia App Developers • Samsung Mobile Innovator • Sony Ericsson Developer World • phoneME	• BlackBerry App World • LG Distribution Channels • Samsung Apps • BlackBerry App Marketplace • Java App Marketplace

The Cocoa Touch layer contains the fundamental infrastructure used by applications such as UIKit framework, which provides the visual infrastructure for applications, and Foundation framework that provides object-oriented support for collections and classes.

The provided interfaces and infrastructures are mostly based on C, Objective-C and mixture of these two languages [Apple 2010b].

The iOS Software Development Kit (SDK) is developed by Apple and it provides the necessary tools for developing, testing, running, and tuning iOS applications. The iOS SDK includes [Apple 2010c]:

- XCode tools:
    - *XCode:* An integrated development environment that enables developer to edit, run, compile, and debug their code.
    - *Interface Builder:* A tool used to create user interface visually.
    - *Instruments:* A tool used for performance analysis and debugging.
- *iOS Simulator:* An application that simulates iOS devices such as iPod Touch, iPhone, iPad in order to test applications.
- *iOS Developer Library:* An environment that provides references and conceptual documents.

2.2 Google Android

Android, an open-source software stack for mobile devices, is controlled and governed by Google Inc. It provides an operating system, middleware and key applications. The latest Android version 3.0 Honeycomb supports multicore processors and hardware acceleration for graphics [Google 2011a].

Android's mobile operating system is based on a modified version of the Linux kernel. The Android software stack consists of Java applications running on a Java-based framework on top of Java libraries running on a Dalvik virtual machine featuring Just-In-Time compilation. The provided libraries are written in C. It includes the surface manager, OpenCore, media framework, SQLite relational database management system, Open Graphics Library Embedded Systems (OpenGL ES), WebKit Layout engine, Skia Graphics Engine (SGL), and Secure Sockets Layer (SSL). Figure 8 depicts the Android system architecture.

The Android SDK includes a diverse set of development tools that enable developers to create applications. The Android Emulator and the Android Development Tools plugin for Eclipse are the most important tools that are supported by the SDK. The SDK also provides a variety of other tools for debugging, installing, and packaging applications. Some of them are listed below [Google 2011b]:

- *Android Debug Bridge:* Manages the state of and emulator instance of Android-powered device.
- *android:* Manages the Android Virtual Device (AVD), projects, and the components of the SDK.
- *Android Emulator:* A device-emulation tool that designs, debugs, and tests an application.

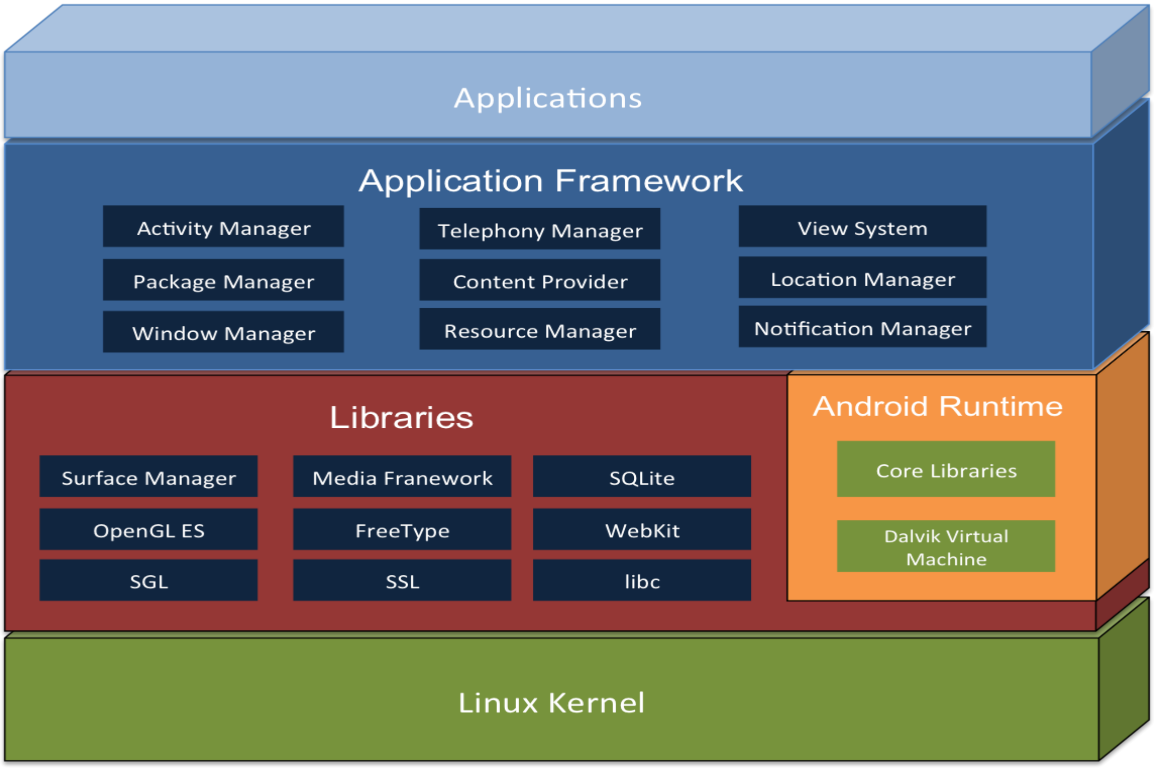

Figure 8. Android system architecture [Google 2011a].

- *Draw 9-patch:* Enables developers to create NinePatch (A class permits drawing a bitmap in nine sections) graphics.
- *Monkey:* Generates pseudo-random streams of user events such as clicks and touches.
- *Layoutopt:* Analyzes the application's layout to optimize it for efficiency.
- *ProGuard:* Optimizes the project code by removing unused code, classes, fields and methods.

2.3 Microsoft Windows Phone

Microsoft Windows Phone (WP) is a mobile operating system developed by Microsoft for smartphones, tablets, e-readers and other devices and is inherited from Windows Mobile platform. It uses Windows Phone 7 operating system as its underlying technology and its architecture is depicted in Figure 9.

The windows phone software architecture contains various components like App Model, UI Model, Cloud integration and Application. The App Model supports licensing, application management, security and software updates. On the other hand, the UI Model, being a page-based UI model takes advantage of the phone's form factor. The shell frame present in the UI Model provides the UI experience and orchestration. The graphics is deeply integrated in the OS hardware stack and uses DirectX capable hardware. The compositor component helps manage applications. The Cloud integration component of the architecture allows us to integrate different Microsoft services such as Xbox LIVE, Bing, and Location. It uses windows Live ID-based authentication. Another component, the Application Runtime is built on Common Language Runtime (CLR). On top of it, three platforms, Silverlight, Xbox/DirectX

New generation Architecture (XNA) and HTML/JavaScript are provided. Silverlight also provides modern animation-based UI. XNA provides a gaming environment for 2D or 3D graphic games. The HTML/JavaScript browser engine gives extra capability for web rendering engine. The framework layer provides the API, which gives access to phone capabilities [Microsoft Corporation 2010b].

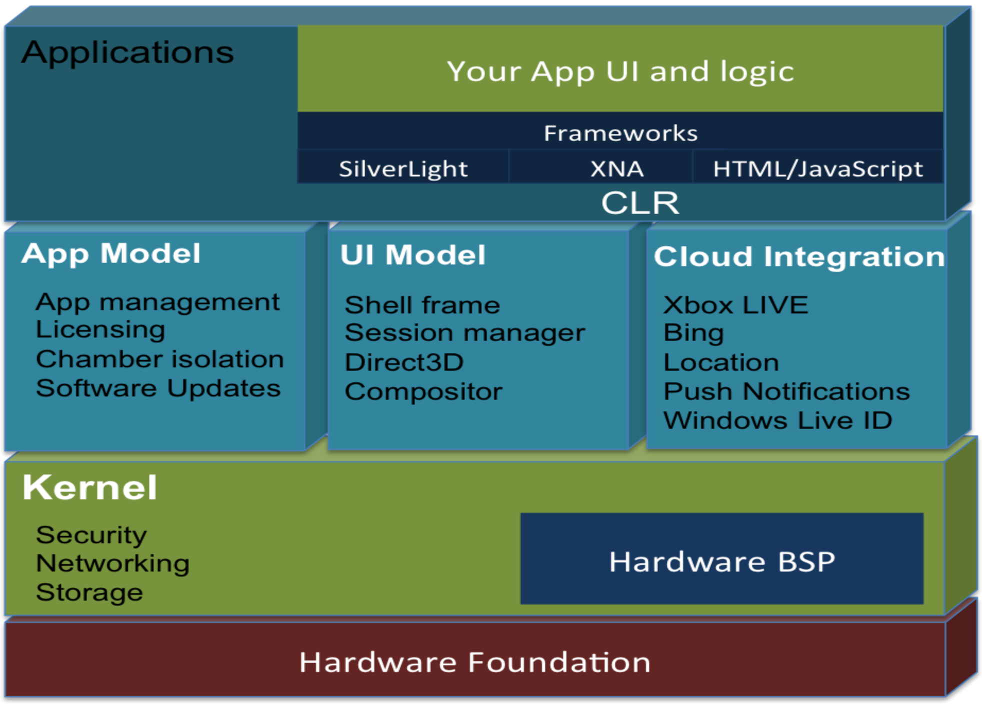

Figure 9. Windows Phone Software Architecture [Microsoft Corporation 2010a].

The Windows Phone Application Platform enables developers to develop engaging applications by providing them with all the necessary tools and technologies [Microsoft Corporation 2011]. These tools are:

- *Visual Studio 2010:* It is an IDE for Windows Phone applications. It enables developer to create either Silverlight or XNA programs. It includes designer, debugger, project system, packager, and manifest generation.
- *Expression Blend:* Enables developers to create Internet applications and Silverlight-based applications. It also allows developers to create XAML-based interface for WP applications.
- *Windows Phone Emulator:* It is integrated with Visual Studio and Expression Blend. It enables developers to test and debug application in an efficient way.
- *XNA Game Studio:* It extends the Visual Studio tools to support the XNA Framework. It provides class libraries and tools for graphical and audio content.
- *Samples, Documentation, Guides and Community:* Helps developers by providing guides, sample code, sample applications, forums, blogs, and websites.

2.4 RIM BlackBerry

Blackberry, a Research in Motion product, is one of the most famous mobile platform services provided in the market. The platform provides two types of services: one for smartphones, called the Blackberry OS, and the other for tablets known as the Quick Unix (QNX) OS.

The latest stable version of the operating system for smartphones is Blackberry 6. It supports new features like multitasking, universal search, gestures and faster web browsing [Research In Motion 2011a]. The other operating system, used for tablets is a Unix like real time operating system and has been specifically developed for embedded systems. It provides multi-core hardware and runs WebKit and Adobe Flash [Research In Motion 2011b].

Blackberry platform supports HTML/HTML5, CSS, JavaScript, and Java. It also enables the use of standard industry development environments such as Eclipse and Visual Studio [Research In Motion 2011c].

Applications, themes, websites and widgets can be developed using various approaches by the Blackberry software development kit [Research In Motion 2011c]. These varied approaches can be combined and used to the advantage of developers. The various Blackberry development approaches are discussed below:

- *Blackberry Tablet OS Application Development:* Enables developers to create Adobe AIR applications for BlackBerry Playbook tablet.

- *Blackberry Web Development:* Enables developers to create browser-based applications.

- *Blackberry Smartphone Themes and Animated Graphics:* Enables developer to create themes, graphics, animated content and splash screen.

- *Java Application Development:* Supports Eclipse, NetBeans and many other Java IDEs and enables developers to create standard-based applications.

2.5 HP Palm

Before HP bought Palm Inc., it was originally a smartphone developer company, which created products such as the Pre and Pix and the Treo and Centro smartphones. After it was bought, the Palm global business unit has made strides in webOS software development and webOS-based hardware products [Krazit 2009].

Figure 10 depicts the webOS system architecture. It can be seen that webOS is an embedded Linux operating system. It hosts a custom User Interface (UI) System Manager built on standard browser technology. A full range of system UI features are provided by the System Manager. These features include navigation, application launching and lifecycle management, event management and notifications, system status, local and web searches, and rendering application HTML/CSS/JavaScript code [Hewlett-Packard 2010a].

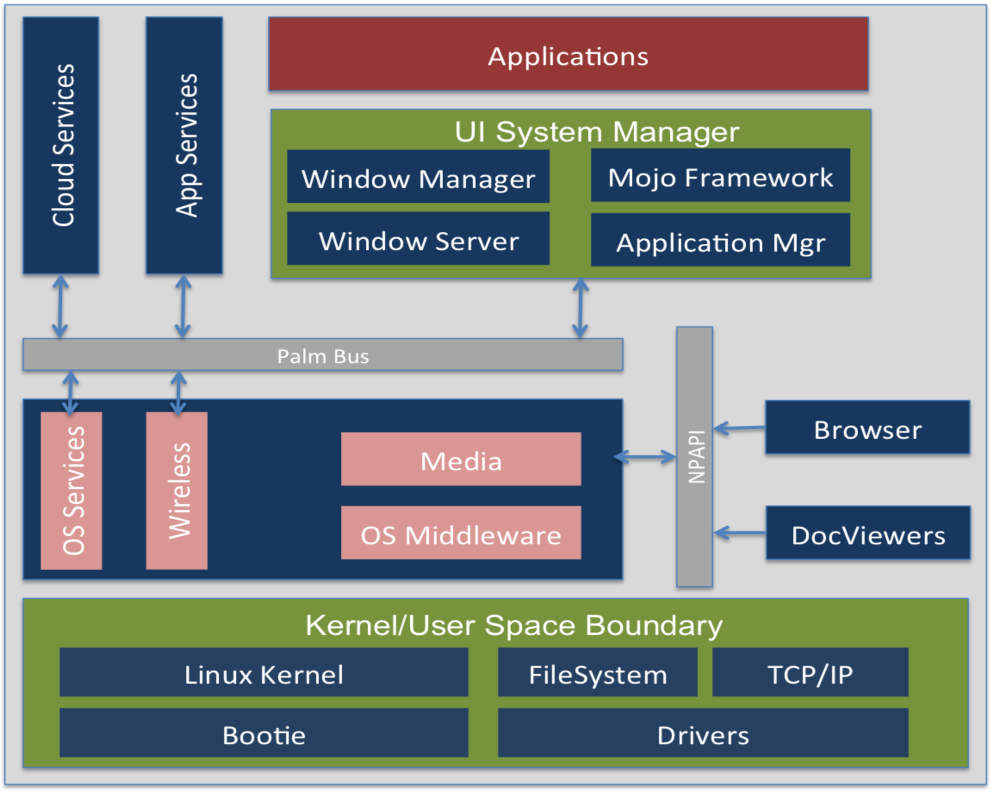

Figure 10. webOS System architecture [Kairer 2009].

The core OS of HP Palm is based on Linux kernel and has standard driver architecture managed by udev. It uses *fat32* for media file partitions and an *ext3* file system for internal files partition [Kairer 2009].

The webOS software development kit includes development tools, sample code, the Mojo Framework, training materials, tutorials and reference documentations. The development tools provide frameworks and sample codes that help developers to create applications and then debug them in the emulator. The webOS developer tools target a variety of different operating systems such as Linux, Windows and Mac OS X. The webOS SDK provides the following developer tools [Hewlett-Packard 2010b]:

- *SDK Bundle Installer:* enables developers to install a variety of different webOS tools.
- *Emulator:* enables developers to use Desktop Emulator and Device Manager.
- *Command-Line Tools:* enables developers to create applications, install and launch apps either in emulator or device. It also allows debugging, inspecting, packaging and signing apps.

2.6 Nokia Symbian

Symbian is one of the most popular smartphone platforms. It supports diverse range of devices. Therefore the flexible structure of Symbian enables developer to create applications for diverse devices right from classic mobile devices to high-end smartphones that interact with users through touch screen.

The Symbian platform uses a Symbian OS, which has flexible architecture as depicted in Figure 11. This flexibility allows different mobile phone platforms to run on top of the operating system. Most widely used model phone platforms are S60 and UIQ.

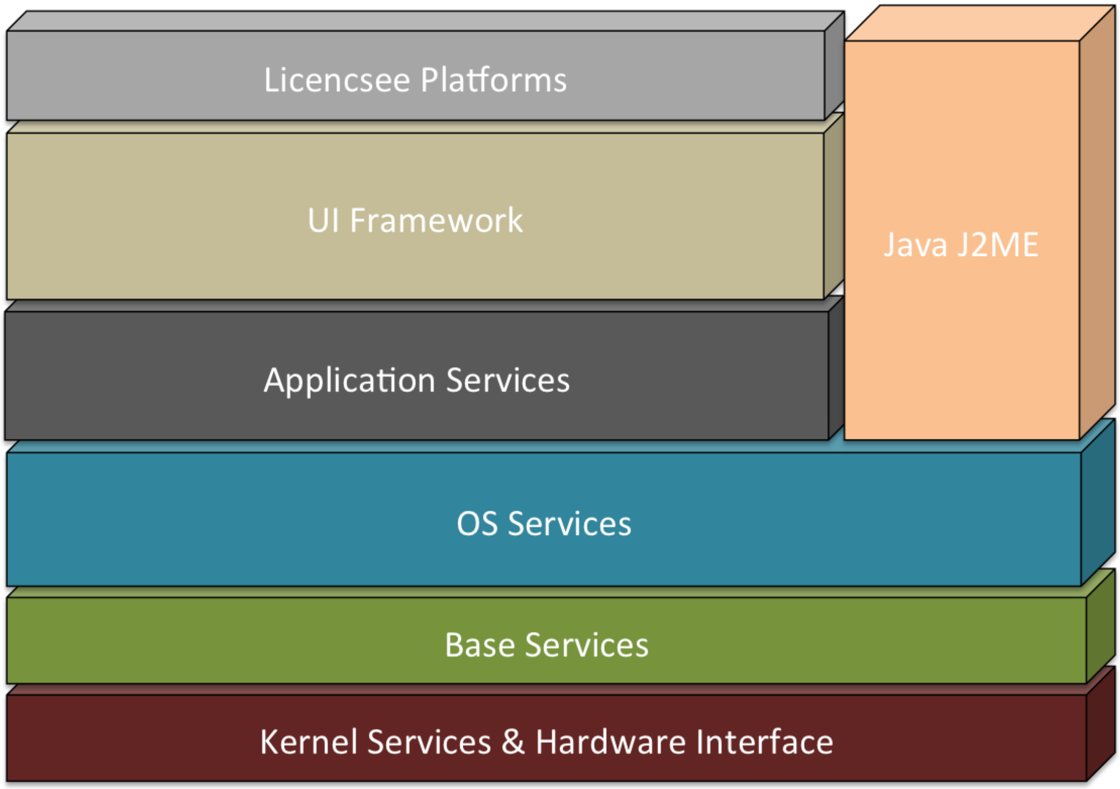

Figure 11. Symbian OS architecture [Symbian 2005].

Symbian Platform provides a graphical user interface (GUI) environment, which helps developers to create additional applications and supply middleware services [Symbian 2005].

Developers can develop applications by using Qt, Symbian C++, set of open C and C++ APIs, the Java language, Web Runtime, and Adobe Flash Lite. In addition to the Flash Lite, the Scalable Vector Graphics-Tiny (SVGT) can also be used for animated contents [Nokia 2011].

Symbian provides uniform implementation of the tools and the corresponding technologies associated with it. This reduces the effort required by the developers [Nokia 2011].

2.7 Java platform Micro Edition (Java ME)

Java ME, originally created by Sun Microsystems, now a subsidiary of Oracle Corporation, is a collection of technologies and specifications that can be combined to construct a complete Java runtime environment specifically to fit the requirements of a particular mobile device. This is very appealing for the end-user as it offers them flexibility and co-existence for all the players in the eco-system to seamlessly cooperate.

The Java ME technology consists of mainly three elements [Oracle 2010a]:

- *Configuration:* It provides the most basic set of libraries and virtual machine capabilities for a broad range of devices.
- *Profile:* It is a set of APIs that support a narrower range of devices.
- *Optional package:* It is a set of technology-specific APIs.

The Sun Java ME software development kit (SDK) combines full support for creating and testing Java ME and JavaFX mobile applications, thereby proving to be a very efficient tool for mobile application development [Oracle 2010b, 2010c].

The Java ME SDK provides device emulation, a standalone development environment, and a set of utilities for rapid development of Java ME applications. There are different software development toolkits that can be used for developing Java ME applications. Some of them are briefly discussed below [Oracle 2010c]:

- *Sun Java ME SDK 3.0:* is considered the de facto standard SDK of mobile application development. The Java ME SDK is the culmination of Java Wireless Toolkit for Connected Limited Device Configuration (CLDC) and the Java Toolkit for Connected Device Configuration (CDC). The Java ME SDK includes an IDE, which can be used to develop and test applications within the same application environment.
- *NetBeans 6.5 IDE:* is an ideal platform, if one needs to work on the visual aspects of mobile applications.
- *MOTODEV Studio for Java ME:* is a Java ME SDK that gives developers several new and exciting features to author, edit, and test mobile applications.
- *Nokia S60, S40, and NFC SDKs:* For Java ME developers, Nokia provides three SDKs to enable the development of the next-generation mobile and wireless applications
- *BlackBerry Java Development Environment (JDE) 4.7:* provides an environment to develop and test mobile applications that run on BlackBerry handsets.

2.8 The Rationale for Selecting the iOS Platform

The iOS development and deployment mobile platform is selected for our work. The iOS platform currently consists of the iPad, iPod touch, and iPhone mobile devices. There are many reasons why the iOS is the best platform for our research work. Some of them are listed below in no particular order.

1. iOS mobile devices are powerful handheld computers that provide computing capabilities similar to laptop and desktop computers.
2. Many K-12 students are already familiar with iPod touch as well as other handheld devices for playing games and listening to music.
3. iOS mobile devices provide a well-human engineered user interface with the state-of-the-art multi-touch technology.

4. Each iOS mobile device contains the Wi-Fi (IEEE 802.11 b/g/n) antenna for immediate wireless access to educational information, resources, and software over the Internet.
5. One unified online store, Apple App Store, is used to distribute iOS software applications (apps) to millions of students, teachers, and others worldwide. The Apple App Store has become the world's largest mobile application platform with over 350,000 apps and 10 billion downloads as of January 2010 [Rosoff 2011].
6. Apple Inc. reviews each developed iOS application, which is submitted to the App Store, and after application approval, the app becomes available to the public on the App Store. Such approval process increases the user confidence in app quality such as trustability, security, privacy, and usability..
7. The iOS platform requires signed code and enforces strict sand-boxing for each deployed application and provides hardware encryption for iOS devices which provide high security.
8. Each iOS device provides an accelerometer (3-axis motion sensor for detecting iOS device orientation and shaking) and iPod touch 4G and iPhone 4 both provide a gyroscope (3-axis for measuring or maintaining orientation). The accelerometer and gyroscope enable the development of more effective games for educational purposes.
9. All iOS devices except iPhone 2G and iPod Touch first generation support latest version of iOS.
10. Each iOS device provides a built-in microphone (voice recorder) and iPod touch 4G and iPhone 4 provide a picture camera and front and back video cameras. The rich and integrated multimedia capabilities of the iOS platform enable the creation of more effective learning environments.
11. iOS mobile devices are affordable (e.g., iPod touch 4G 32GB for $299, iPad Wi-Fi 16GB for $499)
12. Students who own an iOS device can continue their learning at home and on the move using the educational software apps on iOS devices.
13. Using an iOS mobile device for learning purposes generates a sense of ownership by the student, puts control in the hands of the learner, and helps to bridge the gap between institutional and personal learning.

CHAPTER 3: CANDY FACTORY DIGITAL GAME

We developed the Candy Factory as a digital game for the purpose of teaching the concept of fractions to middle school students. It supports developing a model for researching, and implementing the impacts on student engagement, as an innovative educational application, in the mathematics curriculum based on advances in software and mobile computing devices. The main motivation of creating our game is exploring the use of mental operations, such as splitting operation by middle school students. We designed and created the Candy Factory game by using principles from the learning sciences, developmental psychology, and mathematics pedagogy to achieve the most effective teaching and learning application. In addition, it is designed as a universal game application to run on all iOS devices, i.e., iPad, iPhone, and iPod Touch.

In the Candy Factory game, the player's task is to manufacture the candy bar ordered by a customer by using whole candy that is obtained from factory's warehouse. The Candy Factory game starts with a randomly created customer demand of a candy bar, which is a part of whole candy bar. The player is given a whole candy bar, and is expected to reproduce the customer order by partitioning this candy bar and then iterating through appropriate number of times. The level 1 of the game sticks to the familiar part-whole concepts for students to gain understanding of the task. Once the foothold is firm, the players can progress to level 2 and 3. In level 1, the candy bar has existing part markings on the candy bar, which makes it easier for the user. But in level 2 and 3 the candy bar is continuous, without any markings. In order to progress through this level, the players have to make rough estimates of the relative sizes of the bars, using partitioning and splitting operations. The game also has a dragging option which aides the players to make decisions and test their estimations.

3.1 Main Screen

To launch the Candy Factory application, player taps the Candy Factory application icon on the iPad or iPhone. After that, application launches and displays the Main Screen as shown below in **Error! eference source not found.**. In Main Screen, there are four different components. These are the Level 1 button, Level 2 button, Level 3 button and Information button. Each level button enables the player to launch a game based on the chosen level. The Information Button displays the information screen that gives a definition for each level.

The game levels are defined below:

- *Level 1:* Teaches Proper Fractions as Part-Whole concept. A *proper fraction* is a fraction in which the numerator is smaller than the denominator.

- *Level 2:* Teaches Proper Fractions as Whole concept.

- *Level 3:* Teaches Improper fractions, as well as Proper Fractions as Whole concept. An *improper fraction* is a fraction in which the numerator is larger than the denominator.

When player taps any of the level buttons, the application launches a new game as shown in **Error! eference source not found.**.

Figure 12. iPad main screen

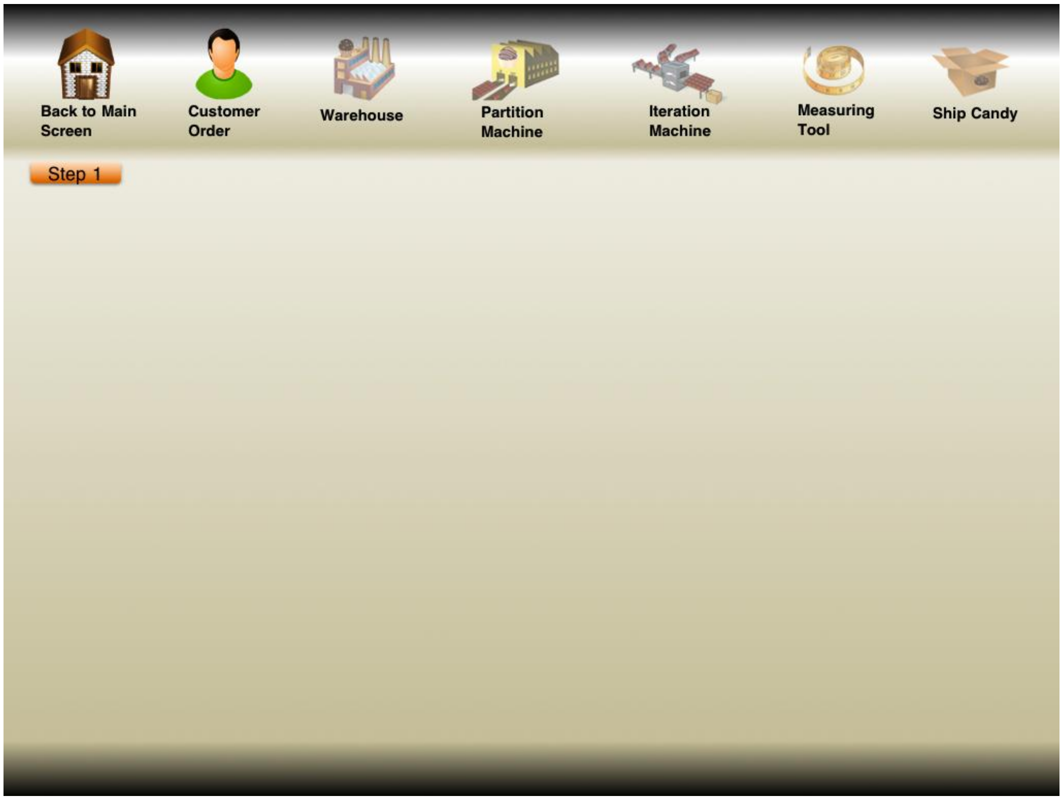

Figure 13. iPad game screen.

3.2 Game Screen

The Game screen is the screen where all players' actions take place such as customer order, getting the candy bar from the warehouse, partitioning, iterating, measuring, and shipping the candy to satisfy customer's order. The Game Screen, shown in Figure 13, has seven menu icons and a Step button as described below

1. *Back to Main Screen:* Enables the player to go back to Main Screen anytime during the game.

2. *Customer Order:* Generates a random customer order and displays the generated customer order on the screen.

3. *Warehouse:* Enables player to select whole candy bars from the warehouse list.

4. *Partition Machine:* Enables player to partition the whole candy bar in as many pieces as needed.

5. *Iteration Machine:* Enables player to iterate the partitioned candy bar as many times as needed.

6. *Measuring Tool:* Enables player to compare the Manufactured Candy with the Customer Order.

7. *Ship Candy:* Enables player to ship the manufactured candy to the customer.

8. *Step Button:* Provides context-sensitive help information that explains what needs to be done for the corresponding step. This help button is provided to implement the user interface design principle that dictates "do not display help information unless the user asks for it."

3.2.1 Game Screen Step 1: Customer Order

A button labeled "Step 1", shown in Figure 14, provides context-sensitive help information upon demand. If the player does not know what to do next, then player taps the "Step 1" button. Tapping the button displays the instructions, as shown in Figure 14. Tapping it again or tapping the background removes it.

After learning what to do for the next step, player taps the "Customer Order" icon, which displays a randomly generated customer's candy order. This candy bar is movable to aid players make decisions and judge their estimations. The step button label changes to "Step 2" for the next step. The generated customer order is displayed with its picture and size based on the game level.

1. If Level 1, the whole-part concept candy, as shown in Figure 15, is displayed with a fraction less than a whole (e.g., 5/8)

2. If Level 2, continuous candy bar, as shown in Figure 16, is displayed with a fraction less than a whole (e.g., 6/11)

3. If Level 3, continuous candy bar, as shown in Figure 17, is displayed with a fraction larger than a whole (e.g., 7/3)

A player can change the randomly generated customer order by tapping the "Customer Order" icon again. This enables players to work with different fractions.

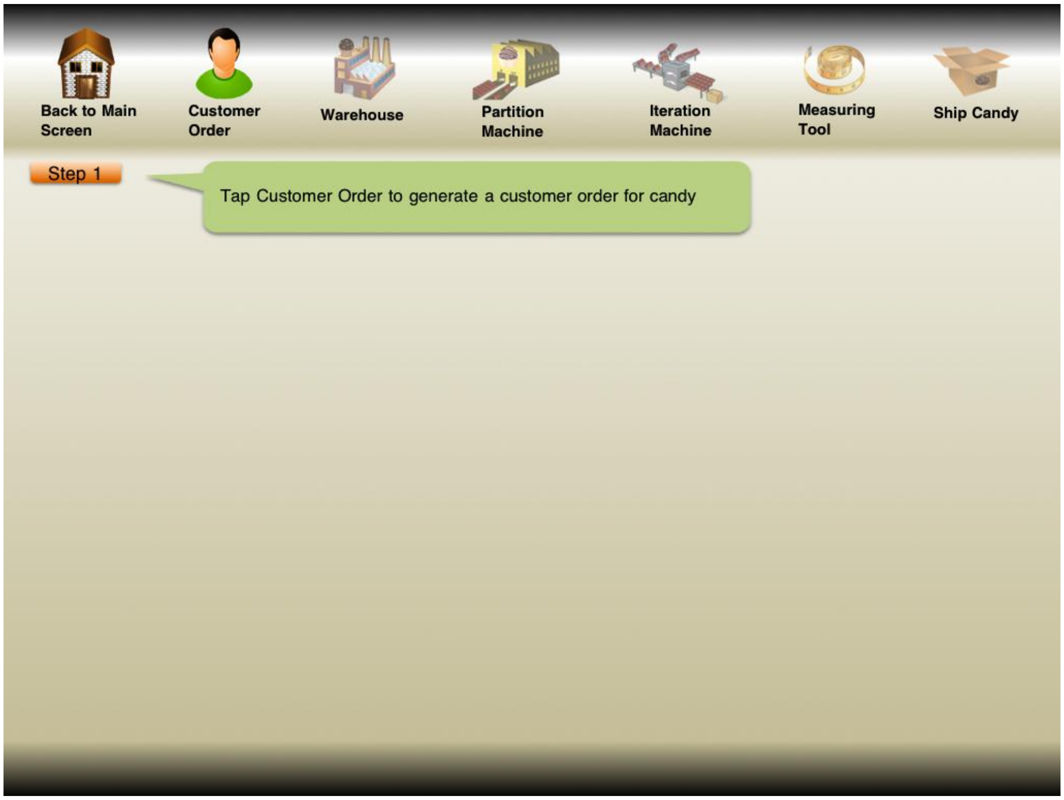

Figure 14. Game screen Step 1

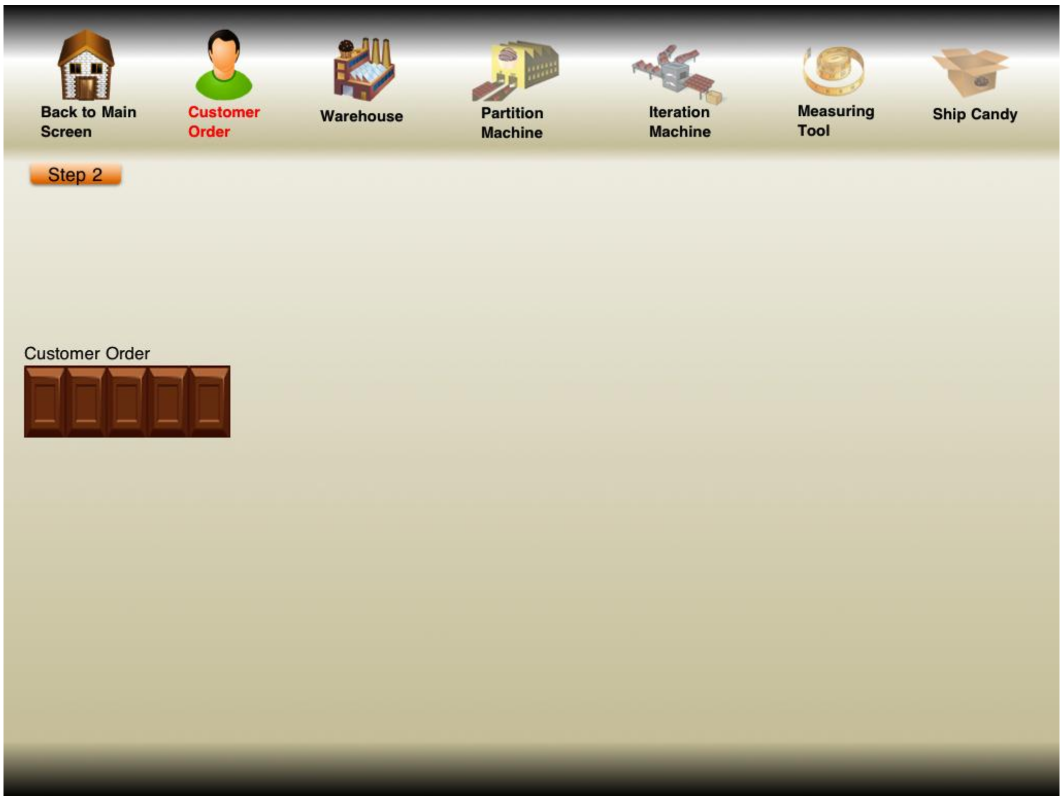

Figure 15. Whole-part concept candy bar

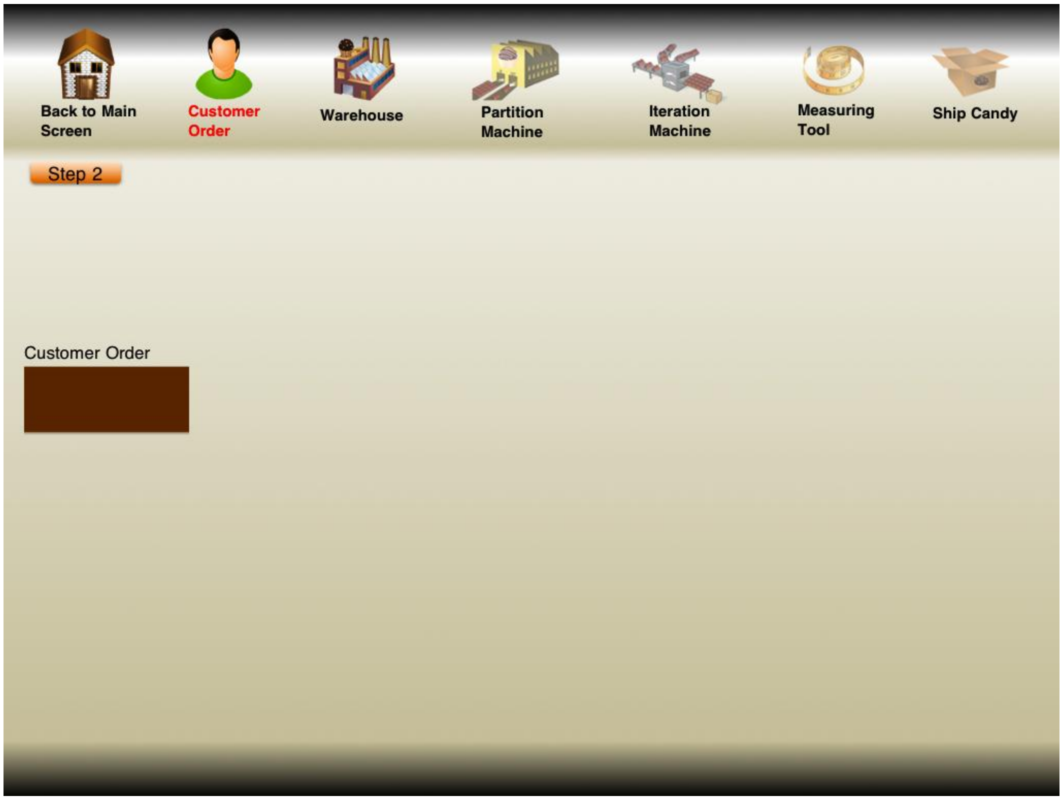

Figure 16. Continuous candy with a fraction less than a whole

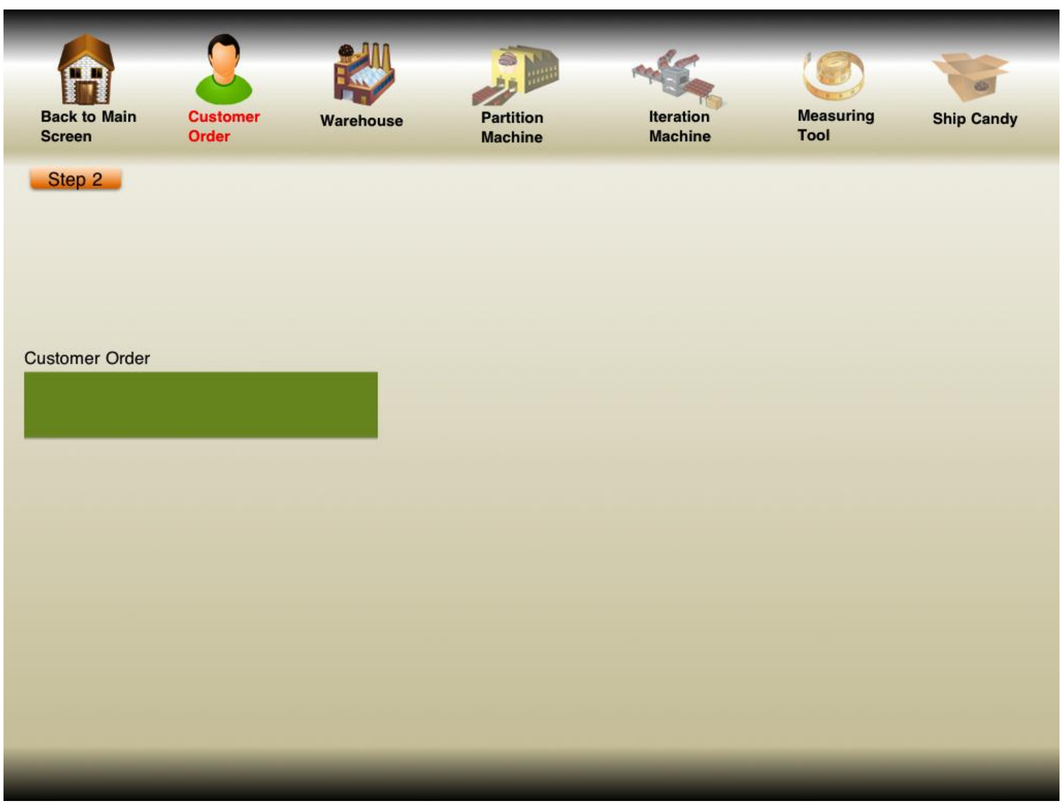

Figure 17. Continuous candy with a fraction larger than a whole

3.2.2 Game Screen Step 2: Warehouse

In step 2, if the player does not know what to do next, he or she can tap the "Step 2" button. Tapping the button, displays the help information as shown in Figure 18.

When the player taps the "Warehouse" icon, the application displays a list of whole piece candy bars, which are available in the factory's warehouse. Depending on the game level selected, the warehouse candy bar list changes as follows:

1. If Level 1, the application displays the six different whole-part candy bars as shown in Figure 19.

2. If Level 2 or Level 3, the application displays five different continuous candy bars as depicted in Figure 20.

The player is expected to select a candy bar from the warehouse list displayed so that it matches the one ordered by the customer.

The warehouse list is displayed as a scrollable list. The user is expected to swipe his/her finger up or down to scroll the listing up or down to see all of the candy bars in the warehouse. During the development testing, we observed that middle school students were unable to notice that the view is scrollable by swiping fingers, got stuck, and did not know what to do. Therefore, we placed a context-sensitive help icon in the upper right corner of the scroll view. Thus, when the player does not know what to do with the scroll view, the help icon can be tapped to get instructions about how to scroll the view as shown in Figure 21.

Selection of a wrong candy bar from the warehouse candy bar list displays the message "Please Try Again" as shown in Figure 22.

Selection of the right candy bar from the warehouse candy bar list, displays the selected whole candy bar, which is movable, at the top of the screen as depicted in Figure 23. In addition, successful selection of a candy bar also changes the current step button label to "Step 3".

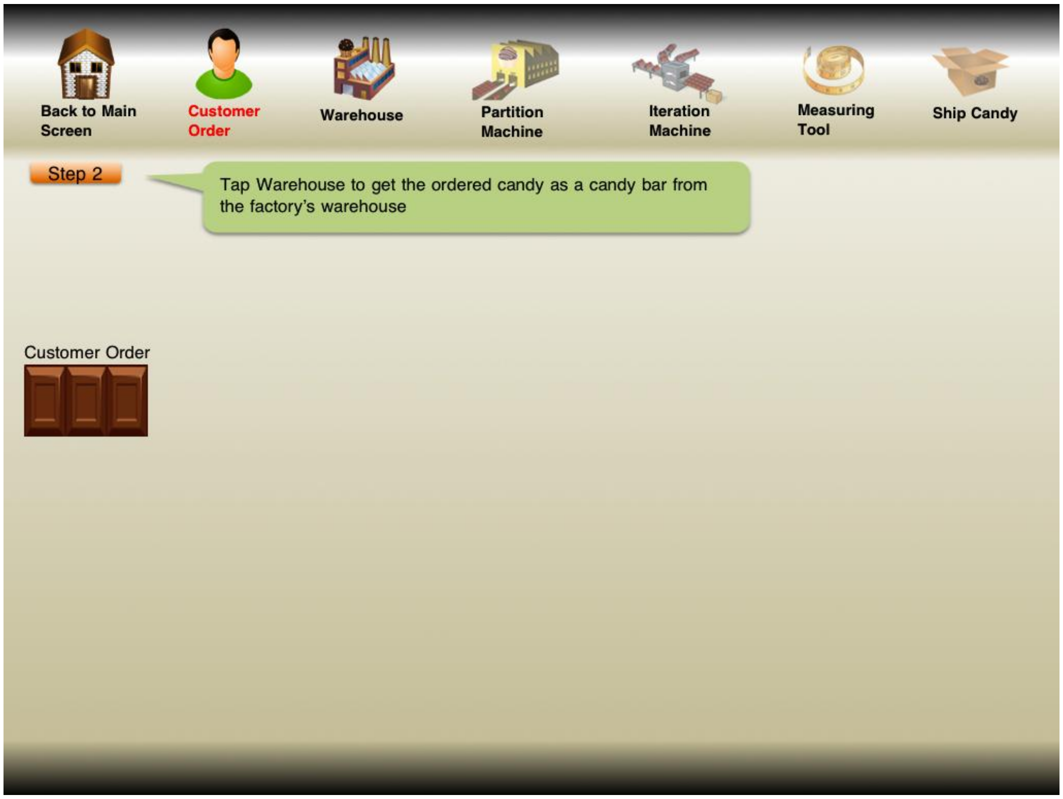

Figure 18. Game screen Step 2 help information

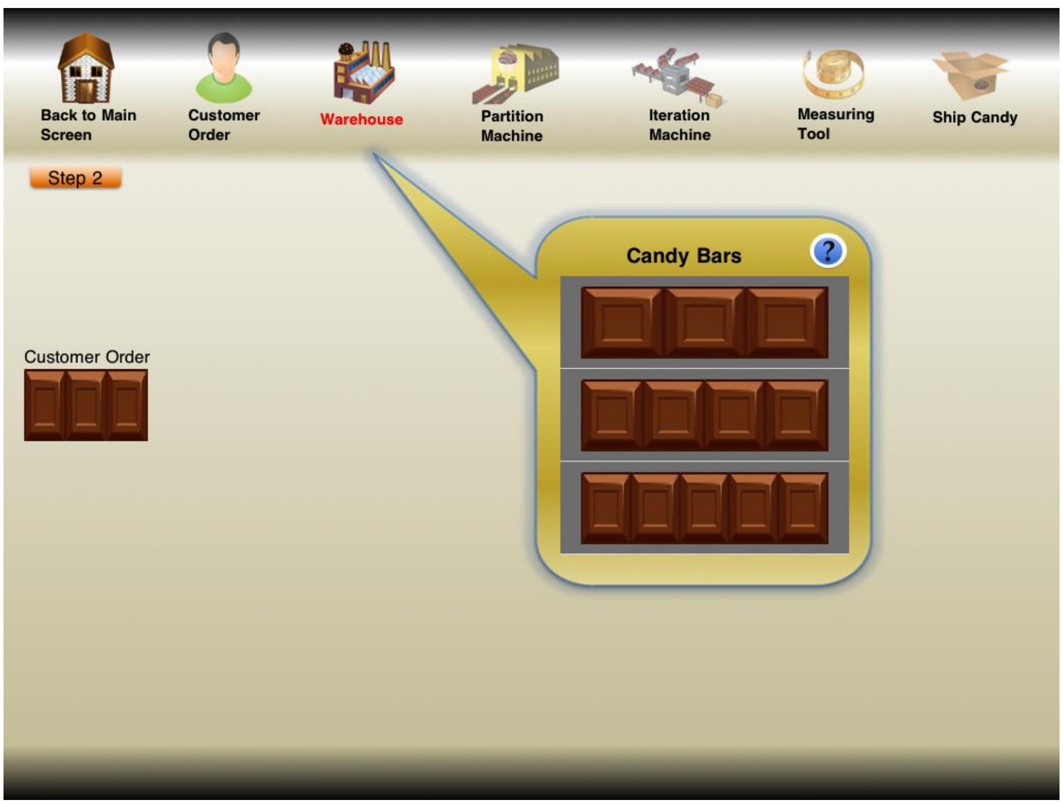

Figure 19. Warehouse whole-part candy bar scrollable list

Figure 20. Warehouse continuous candy bar scrollable list

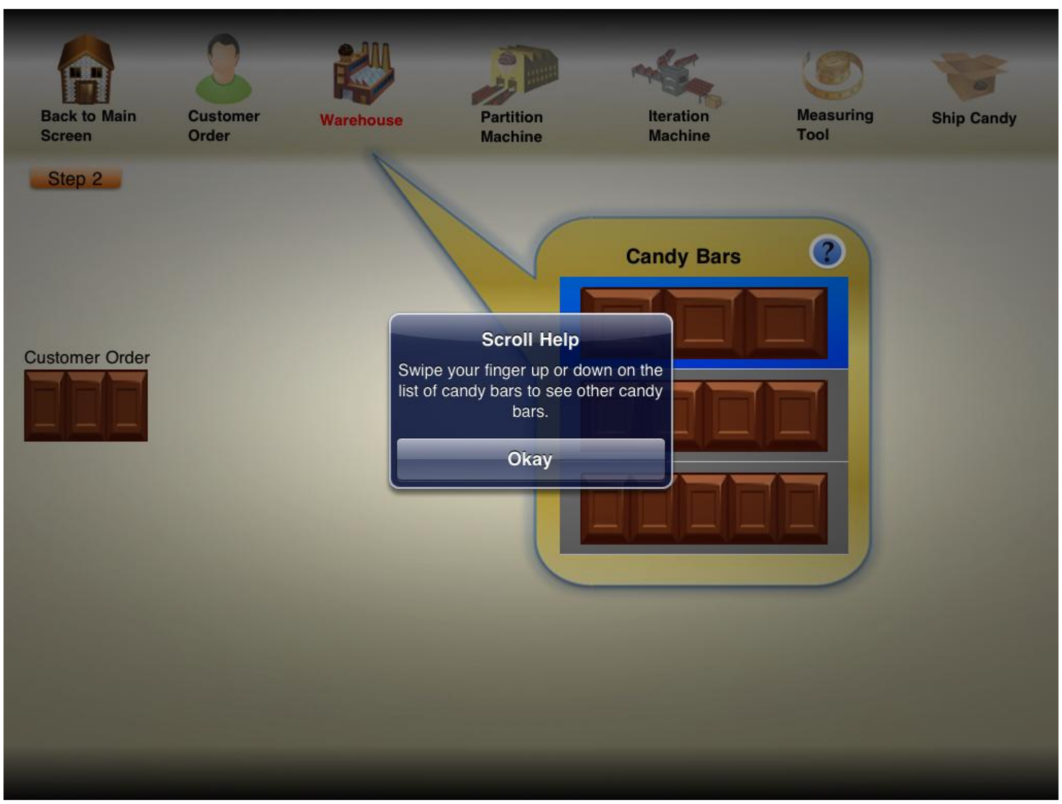

Figure 21. Warehouse candy bar list scroll help

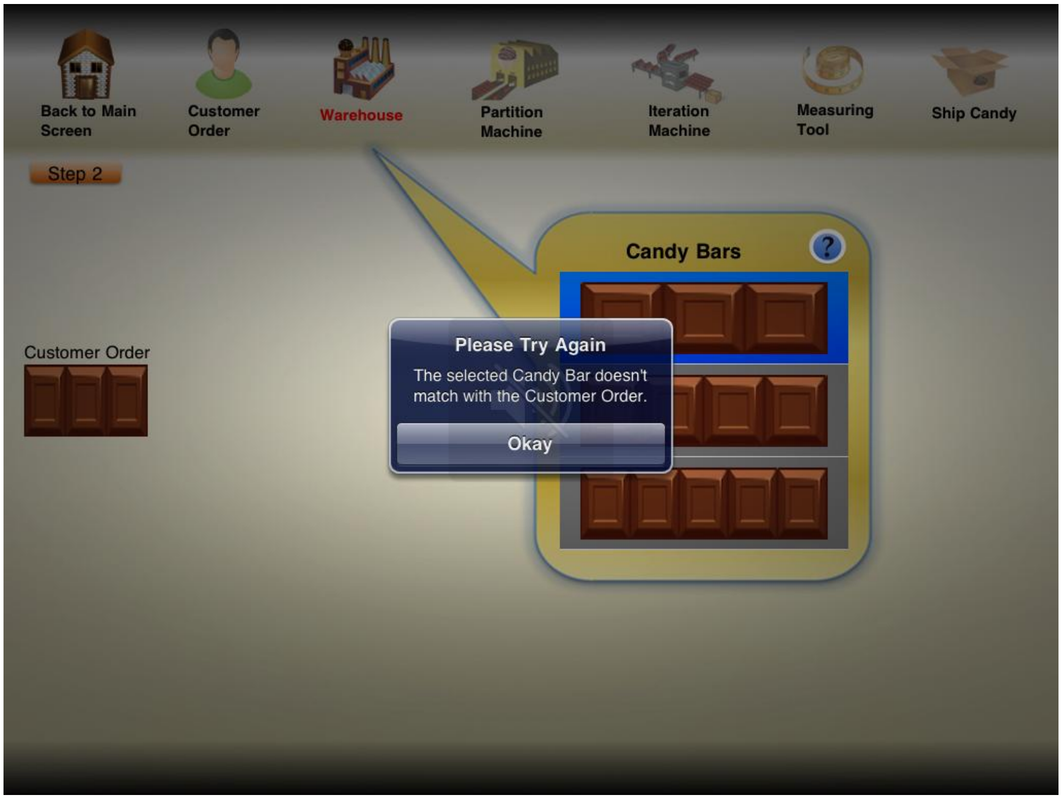

Figure 22. Warehouse candy bar list "Please Try Again" message.

Figure 23. Selected whole-part candy bar

3.2.3 Game Screen Step 3: Partition Machine

In step 3, if the player does not know what to do next, player taps the "Step 3" button. Tapping the step 3 button displays the help information as shown in Figure 24. Tapping it again or tapping the background removes it.

When the player taps the "Partition Machine" icon, the application displays a dialog box listing numbers from 1 to 12 for partitioning the whole candy bar as shown in Figure 25. The player selects the number of partitions from the dialog box by examining the ordered candy's size in comparison to the size of the whole piece candy bar obtained from the warehouse.

Selecting a partition number from the dialog box instantly plays the partitioning animation for the whole piece candy and displays equally broken partitions at the bottom of the screen as shown in Figure 26. Upon completion of the partitioning animation, the step number changes to "Step 4".

After the partitioning animation, player can move the partitions and compare the size of the partitioned candy bar with the Customer Order as shown in Figure 27. If the player decides that the partitions do not match the Customer Order, the player can tap the "Back" button to go to the previous screen. Going back displays the dialog box listing number to slect from for partitioning. If the player determines that the partition size is what is needed, then the player goes to the next step.

Figure 24. Game screen Step 3 help information

Figure 25. Partition machine dialog box

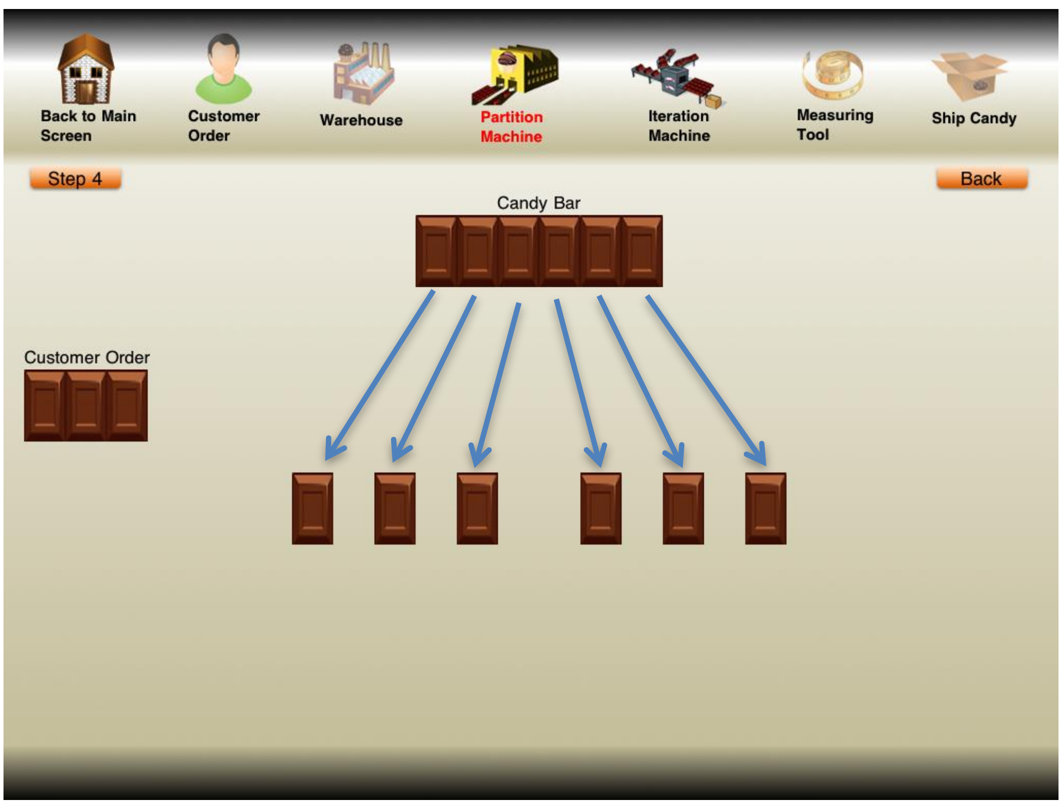

Figure 26. Animated partitioning of the candy bar in equal sizes

Figure 27. Moving partitions for size comparison

3.2.4 Game Screen Step 4: Iteration Machine

In step 4, if player does not know what to do next, then player taps the "Step 4" button. Tapping the button, displays the help information shown in Figure 28.

When the player taps the "Iteration Machine" icon, the application displays a dialog box, which provides the possible iteration numbers to iterate the partitioned candy bar as many times as needed to create a candy with the same size as the customer order. It also displays one of the partitions at the upper right of the screen as shown in Figure 29.

The player selects the number of iterations from the dialog box in comparison of the ordered candy's size with the partition size. Tapping any of the iteration number from the dialog box instantly displays the iteration animation for partitioned candy bar as shown in Figure 30. The selection of iteration number also changes the step button label to "Step 5".

The player can move the iterated candy bar in order to compare its size with the customer order size as shown in Figure 31. If the player finds out that the iterated candy size is different from the customer order, then he or she can tap the "Back" button and reprocess the iteration machine. The step is successfully completed if the iterated candy size matches the customer order size.

Figure 28. Game screen Step 4 help information

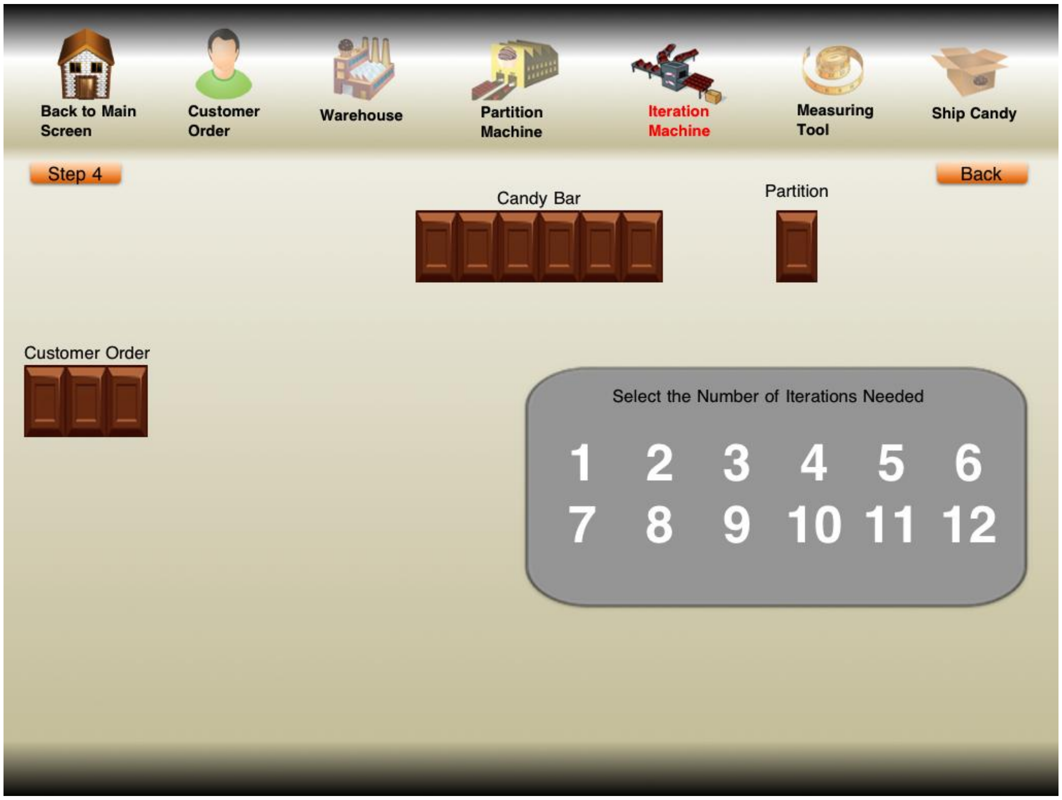

Figure 29. Iteration machine dialog box

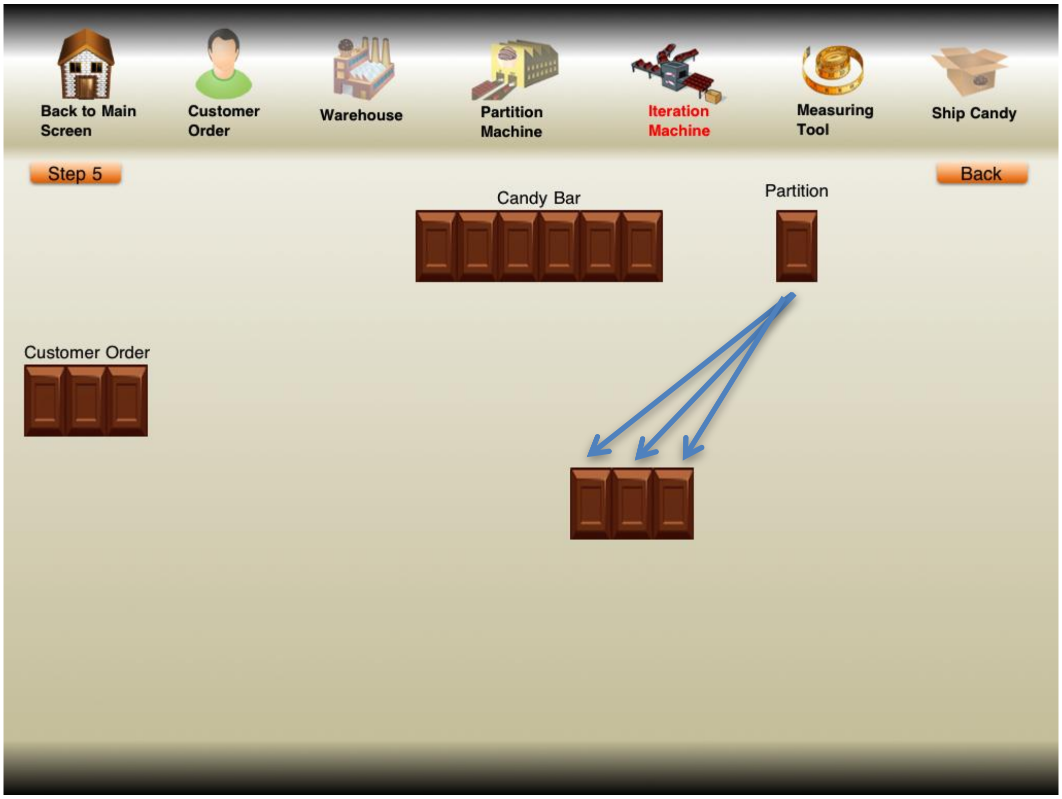

Figure 30. Animated iteration of the partitioned candy bar

Figure 31. Moving iterated candy bar for size comparison

3.2.5 Game Screen Step 5: Measuring Tool

In step 5, if the player does not know what to do next then the player taps the "Step 5" button for help. Tapping the step button displays the help information as shown in Figure 32.

When the player taps the "Measuring Tool" icon, the application displays the "Manufactured Candy" bar as shown in Figure 33. The Measuring Tool enables the player to match the manufactured candy bar size with the customer order one last time, before shipping the manufactured candy to the customer. Measuring Tool enables the player to move either customer order or manufactured candy bar next to each other as depicted in Figure 34.

If the player determines that the manufactured candy bar does not match the customer order, then the player can tap the "Back" button and manufacture the candy bar again. The step is completed successfully when the candy sizes match.

The player can obtain help information about what to do next by tapping the "Step 6" button as shown in Figure 35.

Figure 32. Game screen Step 5 help information

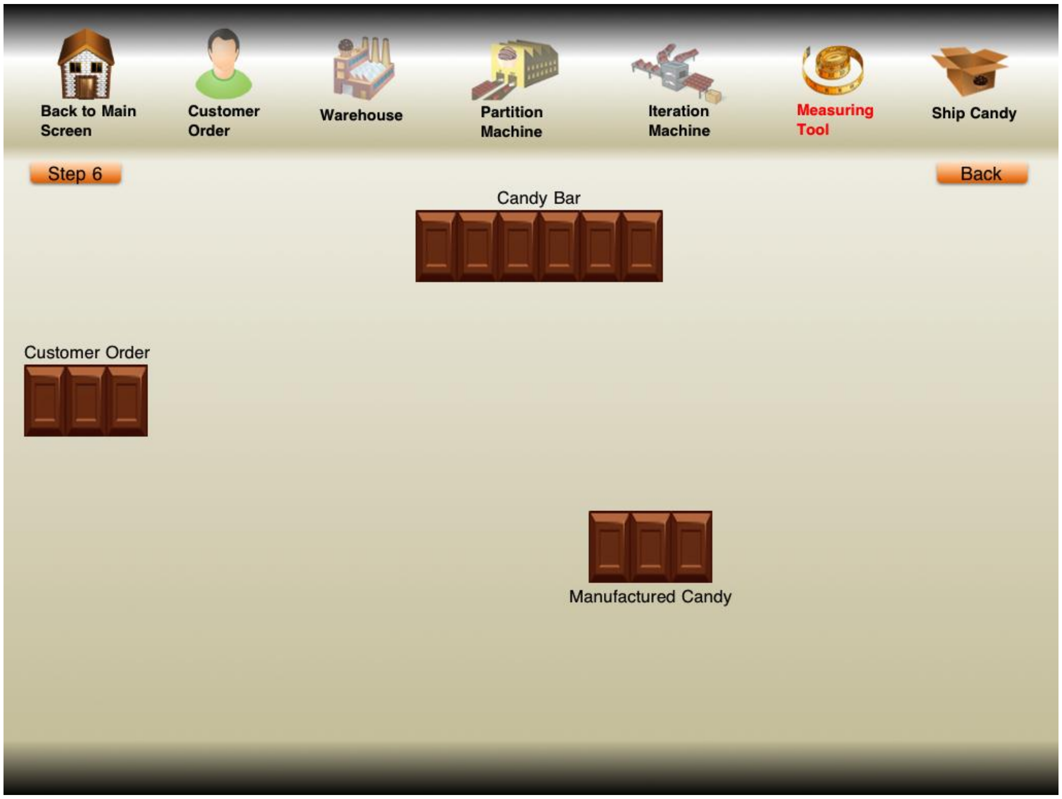

Figure 33. Measuring tool

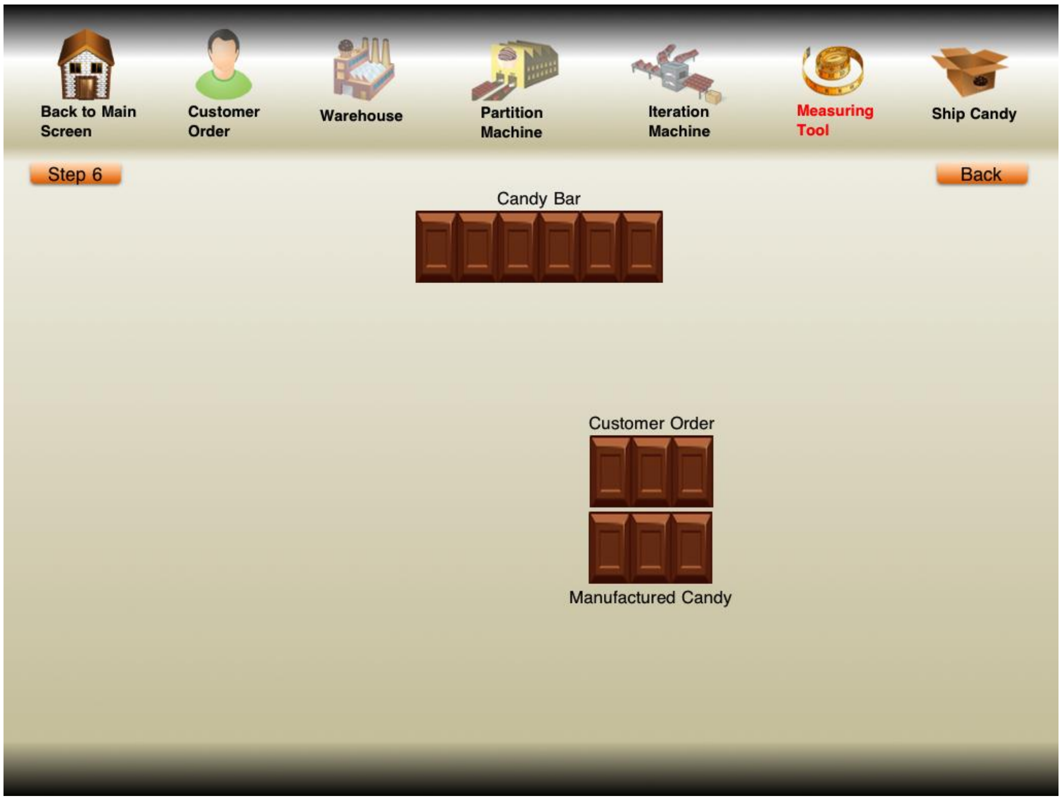

Figure 34. Comparing manufactured candy size with customer order size

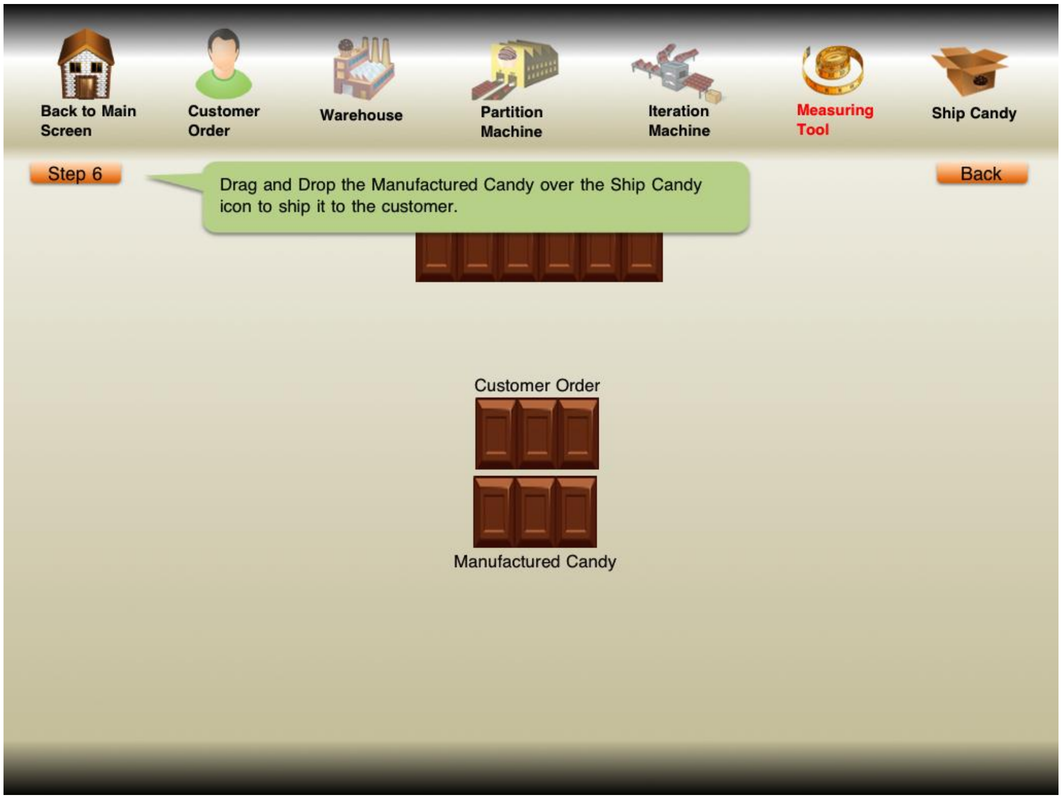

Figure 35. Game screen Step 6 help information

3.2.6 Game Screen Step 6: Ship Candy

In step 6, the player drags and drops the manufactured candy on top of the “Ship Candy” icon as shown in Figure 36 to conceptually ship the candy to the customer.

After dragging and dropping the manufactured candy on top of the “Ship Candy” icon, the application displays a message informing the player for either successful or unsuccessful ending of the game, as shown in Figure 37 and Figure 38.

If the manufactured candy with correct size is shipped, then the application displays congratulatory message as shown in Figure 37. At this stage, if the player wants to play another game, the player taps the “New Game” button and the application displays the “Main Screen” to start a new game.

If the manufactured candy with incorrect size is shipped, then the application displays the message as shown in Figure 38.

Upon unsuccessful ending, the application allows the player to try again. If the player taps the “Yes” button, the application displays the Step 3 screen shown in Figure 39. If the player taps the “No” button, the application displays the Main Screen to start a new game.

Figure 36. Dragging and dropping the manufactured candy to ship it to the customer

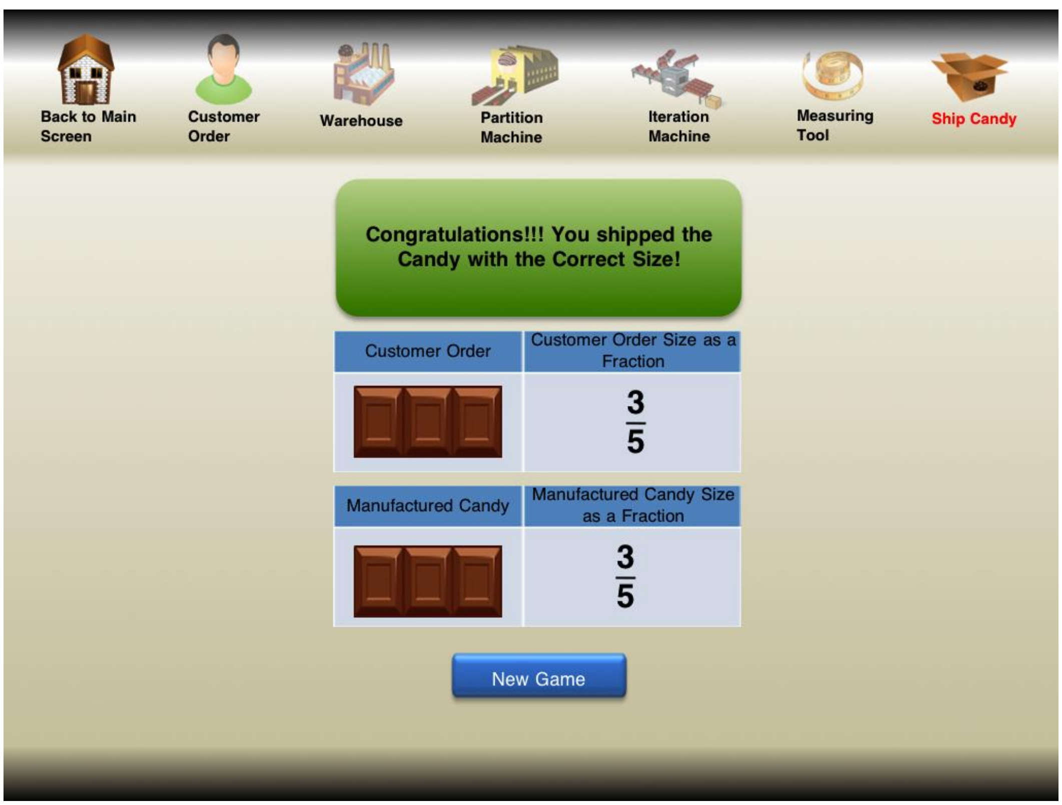

Figure 37. Message for successful ending

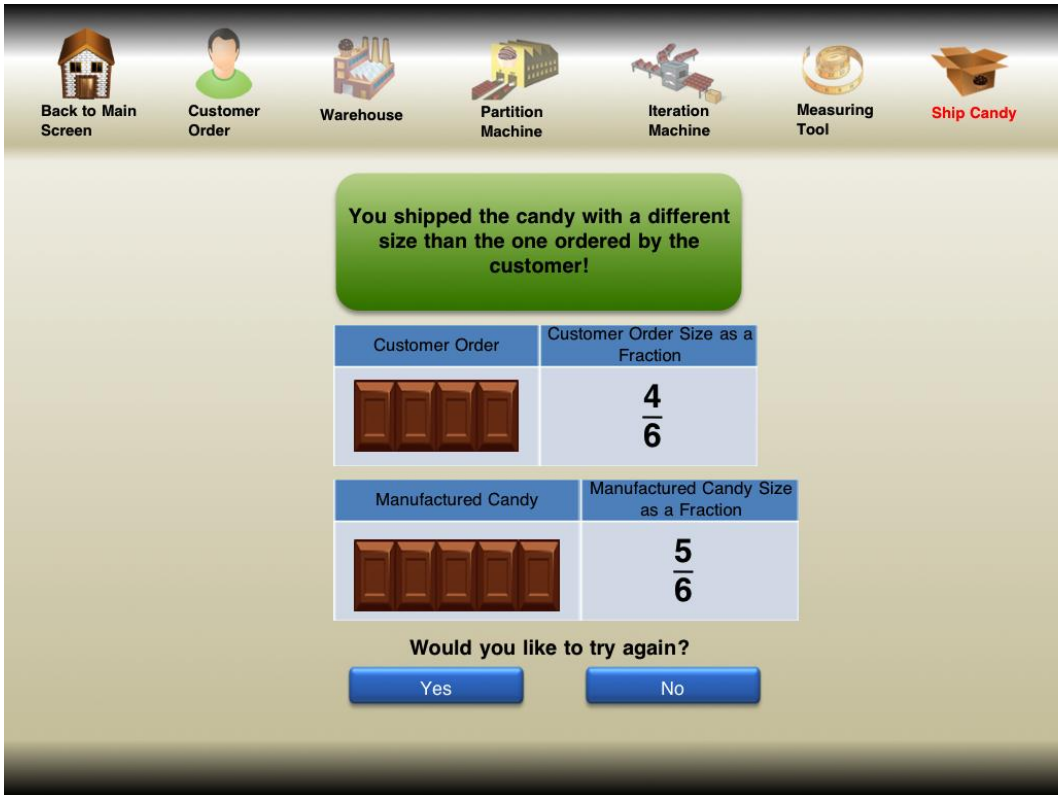

Figure 38. Message for unsuccessful ending

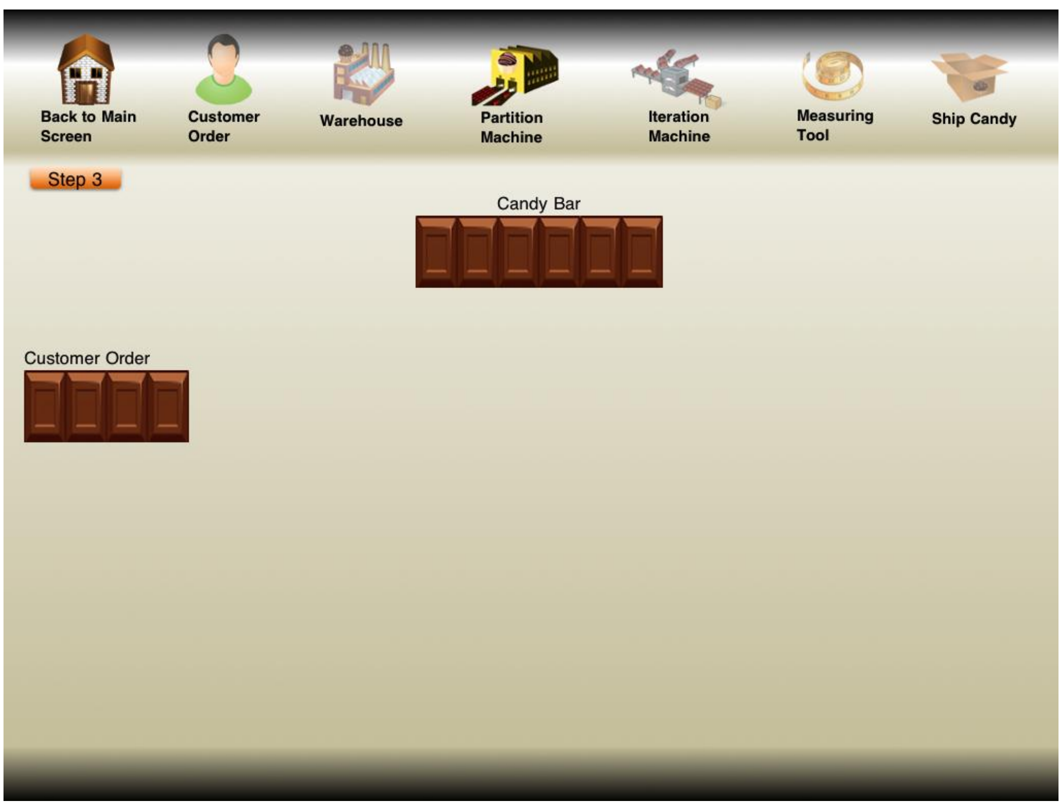

Figure 39. Game screen step 3 for a new trial

3.3 Information Screen

When the player taps the Information button on the Main screen, the application displays the Information screen, as shown in Figure 40. Information screen, defining each game level.

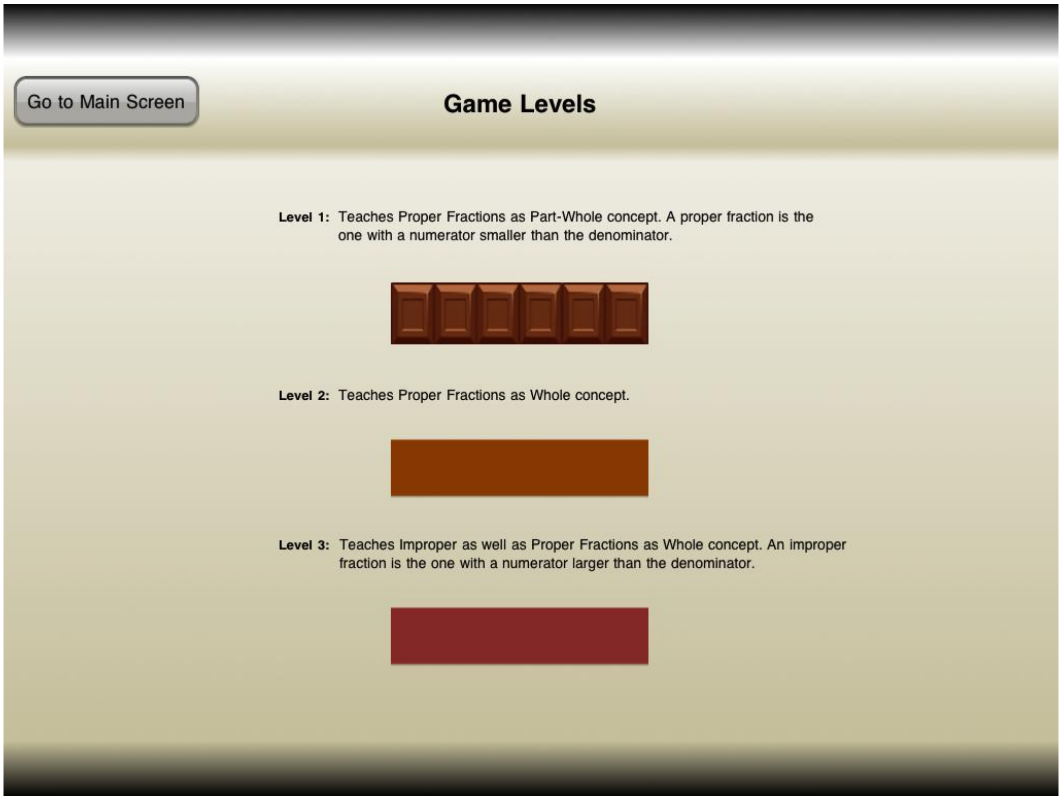

Figure 40. Information screen

CHAPTER 4: SELF-EVALUATION OF CANDY FACTORY

This chapter presents a self-evaluation of the Candy Factory game described in Chapter 3. The self-evaluation is conducted by using the following quality indicators: accuracy, functionality, maintainability, performance, portability, reusability, and usability.

4.1 Accuracy

Accuracy is the degree to which the software possesses sufficient transformational, representational, and behavioral correctness.

1. **Validity**: is assessed by conducting software validation. *Software validation* is substantiating that the software possesses sufficient representational and behavioral accuracy. Software validation addresses the question of "Are we building the right software?"

2. **Verity**: is assessed by conducting software verification. *Software verification* is substantiating that the software is transformed from one form of abstraction into another with sufficient accuracy. Software verification addresses the question of "Are we building the software right?"

We have employed the following verification and validation (V&V) techniques [Balci 1998] for testing the accuracy of the Candy Factory software application:

1. Desk Checking
2. Walkthroughs
3. Beta Testing
4. Debugging
5. Execution Monitoring, Profiling, and Tracing
6. Functional (Black-Box) Testing
7. User Interface Testing

We used Xcode's debugging features and the iOS SDK's Instruments tool for applying some of the testing techniques listed above. The Instruments tool provided effective means for testing memory leaks.

4.2 Functionality

Functionality is the degree to which the software completely captures all of the desired functional modules that need to be present. In other words, functionality checks whether our product meets the intended specifications and functional requirements that are specified in the development process.

We conducted the process of *Requirements Engineering* and identified and specified functional and non-functional requirements for the Candy Factory game. Examining the functionality of the game reveals that most of the functional requirements identified earlier are satisfied.

4.3 Maintainability

Maintainability is the degree to which the software application facilitates changes for:

- adaptations required as the software application's external environment evolves (adaptive maintenance),
- fixing bugs and making corrections (corrective maintenance),

- enhancements brought about by changing customer requirements (perfective maintenance), and
- preventing potential problems or for reengineering (preventive maintenance or software reengineering).

To accomplish the desired maintainability, we developed the components of the Candy Factory game under the software engineering principle of “high cohesion” and “low coupling”. Maintainability of our app is also facilitated by the use of the Objective C object-oriented (OO) programming language. We believe that we have properly applied the OO paradigm to facilitate maintainability.

4.4 Performance

Performance is the degree to which the software executes its work in a speedy, efficient, and productive manner. The following are some of the important performance metrics for the Candy Factory software:

1. *Execution Efficiency:* is the degree to which the software fulfills its purpose without waste of CPU time.

2. *Memory Usage Efficiency:* is the degree to which the software fulfills its purpose without waste of memory.

3. *Storage Usage Efficiency:* is the degree to which the software fulfills its purpose without waste of hard disk space.

In terms of performance, the Candy Factory game works on any iOS devices efficiently, with high speed. Some of the factors contributing to the efficient performance of the Candy Factory game are:

- It is not developed using OpenGL processes, which create heavy load for CPU.

- The memory management is handled manually (no garbage collector), so that memory of the device is not wasted or exceeded.

- It does not have long loading times for launching or starting the game, i.e. requires lesser CPU time.

- Apart from installation of the game to the iOS device, in order to play the game, one does not require any additional storage, plug in or update.

4.5 Portability

Portability is the degree to which the software can easily be transferred from one hardware or software environment to another. Portability helps in cost reduction, when one is targeting several platforms with the same application. It helps provide abstraction between the application logic and system interfaces.

The Candy Factory game has been created as a universal application to run on all iOS devices, i.e., iPad, iPhone and iPod Touch. Porting the game app from one iOS device to another is resolved.

Porting the game app to other mobile engineering platforms, specifically, to Android, Windows Phone, and BlackBerry remains to be challenging, but doable. All of the mobile software engineering platforms use an object-oriented programming language, which should facilitate portability.

4.6 Reusability

Reusability is the degree to which the software facilitates the reuse of its components in the development of other software products.

We have properly applied the object-oriented paradigm (OOP) to facilitate reusability. The reusability and maintainability quality characteristics are typically achieved by proper application of OOP.

4.7 Usability

Usability is the degree to which the software can easily be employed for its intended use.

The Candy Factory game has been designed and implemented for use by middle school students. Before starting the design process of the Candy Factory application, the games available on the Internet and Apple App Store were analyzed. Their drawbacks and advantages were studied, and the findings were incorporated while designing the application. Simplicity was the key. The user interface and rules for the game were kept as simple as possible.

When the player launches the game, the player can directly start playing the game without having to read a list of long instructions. In case the user feels the need for any guidance, each game screen provides a help button labeled as Step, which explains what needs to be done at that particular step.

The game is functionally decomposed into three different levels, each focusing on a different fraction operation with different level of difficulty. The game is made more user friendly, interactive and engaging, by making the candy bar objects movable so that the player can easily match and compare the objects on screen. This helps them make more accurate predictions and get better results. Thus, simple separation of six different steps, straightforward instructions for each step, and user-friendly interface makes the software more usable.

The Candy Factory game's usability was tested by having some middle school students use the app on an iPad. The students' interaction with the game app was recorded in a video. We analyzed the video and identified improvements. For example, in an earlier version of the app, students were stuck when they were presented with a scrollable table view of candy bars, because they did not know that the table view is scrollable. We placed a context sensitive help button to provide the needed help.

CHAPTER 5: CONCLUSIONS AND FUTURE RESEARCH

5.1 Conclusions

This thesis describes the research and development of a digital game, called Candy Factory, which provides a game-based innovative approach for teaching fractions to middle school students. The currently available digital games mainly focus on either part-whole concept or fraction operations and do not use any nonconventional techniques to teach the fundamentals of fractions. The Candy Factory game has overcome this limitation by using the concept of splitting operation to teach improper fractions.

For an educational game to be successful, apart from emphasizing the learning, it should be entertaining, as well as engaging for students to truly benefit from it. We aimed to achieve this amalgamation by designing a game for Apple iOS mobile devices, which uses advanced graphics, multi-touch technology, and well designed game interface to help students learn the concept of fractions in an enjoyable manner with sustained interest.

The Candy Factory game is developed as a universal application to run on all iOS devices, i.e., iPad, iPhone, and iPod touch. The development was carried out under a proven software engineering life cycle by employing best practices and object-oriented software design patterns. The life cycle started with Problem Formulation and Requirements Engineering. Upon creation of an App Design based on the requirements specification, we conducted Design Reviews through which the design has gone through "iterative refinement" and "progressive elaboration". The final design was implemented in Objective-C programming language using the Xcode 4 integrated development environment. The app has been tested using a variety of software verification and validation techniques.

Evaluation of the Candy Factory game revealed that it possesses most of the desired features a good game should have. It has clear objectives and well-defined simple rules, which result in straightforward outcomes. The game provides the user with an interactive, realistic and relevant environment. The Candy Factory game makes the learning experience enjoyable by providing real life situations, which help the student gain hands-on learning experience.

5.2 Contributions

The major contribution of the research and development described herein is the creation of an interactive digital game with multi-touch technology to teach middle school students the fundamental concept of fractions. When published at Apple's App Store, our digital game Candy Factory will be delivered to millions of students on all iOS devices, i.e., iPad, iPhone, and iPod touch. Our digital game is believed to improve the effectiveness of learning fractions. Since the new generation of middle school students are obsessed with digital games, they should also be interested in playing our digital game Candy Factory through which they can learn fractions more effectively in comparison with the traditional paper-and-pencil teaching approaches.

5.3 Future Research

The Candy Factory digital game is designed to teach the concept of fractions in an interactive and enjoyable manner to students. We aim to extend our research by studying in greater depth the effect of Candy Factory game at various levels and on diverse groups of students. This data collection would help us arrive at more accurate conclusions about the effectiveness of the game and help us improve it.

The game can be improved to adopt personalized pedagogy by using a robust game-based, mobile device-centric platform that allows for continual embedded assessment that keeps track of each individual student's learning curve and modifies the root of the game accordingly. The game can also be extended such that it can cater to children with special needs, by using modified user interfaces and modes of interactions.

The Candy Factory digital game can be improved by providing the following:

1. Sound effects in addition to the existing visual effects.
2. Adding animated opening screen before the main screen.
3. Providing different game themes.
4. Allowing the student to select a game level only if the previous one is successfully completed.
5. Adding "Timer", "Score" and "Lives".
6. Improving menu icons by providing better design.
7. Providing "Info" button in another dedicated screen.
8. Modifying the layout of the game screen to provide a separate region for the "Step" button, such that it does not intrude the playing area.
9. Improving selection of game menu icons such as instead of highlighting the text, providing some visual effects.
10. Rewarding correct answers and penalizing incorrect answers.

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