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Russian Mathematical Pedagogy in Reasoning Mind

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Abstract

Reasoning Mind (RM) incorporates aspects of Russian mathematics pedagogy and curricula into its online math program. Our investigation identifies typical attributes of Russian pedagogy discussed in news articles and publications by Russian education experts, then determines how these attributes arise in RM. Analysis of RM's implementation of the characteristics reveals more successful inclusion of curricular attributes than classroom strategies. Thus, we outline classroom techniques that could be assimilated into RM to provide a more Russian learning experience along with students' exposure to Russian-style curricula.

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Acknowledgments

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Chapter 1

Introduction

New ideas in mathematics education are constantly proposed and tested in an effort to improve student learning. A nonprofit organization, called Reasoning Mind (RM), has incorporated Russian curricula and pedagogical ideas into computer-based learning (CBL) in an attempt to increase student achievement in elementary school mathematics. RM claims to give its American users a learning experience built around Russian pedagogy. Here, we explore the question of how to assess the validity of such a claim and also investigate the extent to which the claim is true.

In order to identify how and where these Russian characteristics are incorporated into the RM program, we launch a multifaceted investigation of Reasoning Mind, detailed in Chapter 2. First, since the RM program consists of computer-delivered curriculum, we examine research on computer-based learning to help situate Reasoning Mind in the educational landscape. Thus, we are able to identify novel as well as standard aspects of the program. Second, through direct interactions with both the student and teacher interfaces in RM and conversations with RM Knowledge Engineers and curriculum specialists, we familiarize ourselves with the RM program and curriculum. Third, we examine a data set from a real implementation of RM and thus gain intuition about how students utilize the program. Finally, we investigate data showing the distribution of problem types shown to the students in various parts of the program compiled through work in the system. All of this knowledge about Reasoning Mind contributes toward our ability to assess the appearance of different Russian characteristics in the system.

Next, we must decide how to identify pedagogical ideas to label as Russian. In Chapter 3, we investigate what aspects of pedagogy and curriculum could be considered Russian by exploring multiple sources, including the history of Russian mathematics education, personal accounts of Russian versus American education, and two texts which have influenced RM's interpretation of Russian curricula. Based on this work, we compile a list of Russian teaching characteristics, including classroom aspects and curriculum attributes.

Finally, we present an analysis of the Reasoning Mind system through the lens of Russian pedagogy. Various aspects of RM are clearly influenced by Russian curricula, while some Russian pedagogical techniques are yet to be incorporated into the system. Overall, Reasoning Mind has found success in implementing Russian curricular ideas, but is still working to incorporate Russian classroom techniques. Within the time frame of the current project, several shortcomings have been remedied, while other solutions are still in progress. Reasoning Mind represents a novel computer-based approach to improving elementary mathematics education and proves to be committed to bringing Russian pedagogical ideas to the American classroom.

Chapter 2

Reasoning Mind

Reasoning Mind combines aspects of Russian mathematical pedagogy with a computer-based learning environment. The concept of computer-based learning (CBL) has existed "in the United States [since] the late '50s and early '60s" (Chambers and Sprecher, 1980). However, CBL has faced obstacles and has not been widely adopted for everyday use by teachers. Across classrooms, the extent to which computers are used for learning varies. Teachers might present lecture notes on a SmartBoard or digitally project notes from a tablet computer. On the other end of the CBL spectrum are classrooms with students who learn exclusively using curriculum delivered by a computer. Increasingly, cyberschools allow students to learn from home, while connecting with content, teachers and other students exclusively online. Often CBL implementations lie somewhere between these extremes with traditional classrooms incorporating CBL programs into their normal curricula.

In 2008, the National Mathematics Advisory Panel noted the promise of computer-based learning stating that "instructional software has generally shown positive effects on students' achievement in mathematics" and "[CBL] tutorials have been used effectively to introduce and teach new subject-matter content" (Faulkner et al., 2008). Other proponents of CBL list myriad benefits. CBL leverages children's natural affinity to technology as a way to engage them in mathematics or other subjects. Additionally, when course material is presented by a computer, teachers are able to focus on individual student learning. For example, they can address questions as students work through the material on their own (Reasoning Mind, 2011). Students work at their own pace and receive individualized instruction (differentiation) and homework (Waxman and Houston, 2008).

The computer fills the role of giving "continual feedback and assessment" (Wijekumar et al., 2009). Because the most modern programs are hosted online, they can be accessed from any computer that has an Internet connection. Students can work after normal school hours at home or at the library, if they choose. Finally, since the program monitors student learning, it can diagnose weaknesses and misconceptions, then remedy them before the student moves on to more advanced topics (Weber, 2006).

Some drawbacks to CBL have also been identified. Many of these drawbacks suggest reasons why CBL is not adopted in schools (Weber, 2003). One of the largest obstacles faced by CBL is the effort required by and apprehension toward converting to a new unknown teaching method (Chambers and Sprecher, 1980; Moonen, 1987; Yeloushan, 1986). The cost of computers also can be a large stumbling block. For most CBL programs, each student needs their own Internet-connected computer. Reliable access to the Internet can be an additional problem (Weber, 2006). Furthermore, in order for CBL to be adopted in a school for everyday use, it has to be approved as a curriculum by the government, meaning that it has to meet strict standards (Reasoning Mind, 2011). This requirement makes large-scale in-classroom testing difficult and this can slow the adoption of CBL in schools.

In extreme opposition to CBL, there are some schools, such as the Waldorf schools, which intentionally exclude technology from their classrooms. Proponents of the Waldorf school have said, "Technology is a distraction when we need literacy, numeracy and critical thinking" (Richtel, 2011). Instead of leveraging students' attraction to technology, these schools want to postpone use of technology. Computer-based learning is inherently opposed by Waldorf schools.

As a CBL program, Reasoning Mind enjoys the advantages listed above and must overcome the associated disadvantages.

2.1 Introduction to Reasoning Mind

There are a vast number of computer-based learning systems in the educational market today. However, it is difficult to identify which systems are most effective and professional organizations like the National Council of Teachers of Mathematics do not endorse commercial products (NCTM, 2011). Additionally, no national lists of top-selling or most-used mathematics computer software were found. In a sea of products, different software companies must distinguish themselves in some way. Reasoning Mind stands out because of Russian influences on its curriculum.

Reasoning Mind (RM) is a nonprofit organization founded by Russian-American Alex Khachatryan. Khachatryan's son showed little interest in science and mathematics as a child. In response, Khachatryan created a computer program to pique children's interest in science and mathematics by leveraging the fondness that children show for computers. He "decided to take a curriculum that had been proven effective in other countries like the Soviet Union and build an expert system to deliver the curriculum to students" (Mitra, 2009). Specifically, Reasoning Mind has created an elementary school mathematics curriculum. The computer-delivered curriculum from RM is accessed online (Weber, 2006).

Reasoning Mind aims to serve the classroom as a whole, and support the CBL and non-CBL aspects of its classrooms. The organization provides training for teachers who use Reasoning Mind as well as tutors for students, who can be contacted through the RM interface. These services make RM more than a standalone CBL website; it relies on the teacher to manage the classroom and answer student questions individually or in small groups.

Reasoning Mind serves students in five states, Texas, Oklahoma, Missouri, Louisiana, and California, although the majority of their students are in Texas and California. Eventually, the company hopes to scale up to have students in all fifty states using their curriculum. So far, the spread of Reasoning Mind has been intentionally slow, with the organization taking care to ensure that the scaling of the project retains its integrity. In particular, it is necessary to ensure that the teachers all are trained adequately and that there are enough tutors for all of the students (Reasoning Mind, 2011).

Reasoning Mind currently has implemented curriculum for grades two through six. This corresponds to elementary school, grades 1 through 5, in Russia. Some schools in Texas have adopted the fifth and sixth grade curricula. In these schools, the RM program becomes the core curriculum that is taught in math classes as the students' normal math class. All other implementations of Reasoning Mind are considered "supplementary," meaning that the students receive traditional mathematics instruction in addition to time using Reasoning Mind (Randall, 2011).

In order to gain an understanding of Reasoning Mind's implementation, I explored both the student and teacher interfaces. The student view of the RM program is organized around the structure of a city, "RM City," that has different buildings which the student can explore (see Figure 2.1). The student is greeted and led through the program by an animated character called the Genie. RM City's buildings include Guided Study, Wall of

Figure 2.1 When students log onto the system they see a home screen of RM City.

Mastery, Homework, My Points, My Place, a Library, a Post Office, a Shopping Mall, and a Game Room. Many of these buildings (Shopping Mall, My Points, and My Place) support the reward system that is built into RM where students gain points for answering questions correctly. Students can spend points at the Shopping Mall to decorate their Place. Points can be earned by correctly answering streaks of several questions in succession or answering quickly on timed questions. Students can track their progress in the My Points building. Completed topics can be reviewed on the Wall of Mastery, which has additional problems of three levels of increasing difficulty. In the Post Office, students can email their teacher, tutors or their animated guide, the Genie. The Library contains mathematics resources such as multiplication tables, a glossary of mathematical terms, and other virtual math books. Students can play math skill games in the Game Room either individually or against each other. Students enter their answers to the previous day's homework in the Homework building.

I also gained insight into how Reasoning Mind is used by students from

Figure 2.2 Animated characters tell a story and ask the student questions.

three of RM's analysts, Alex Randall, Anika Huhn, and Victor Kostyuk. The majority of the students' classroom time is spent in Guided Study (Randall, 2011). There, students view theory material and try practice problems. Whenever students log into Guided Study, they are given some warm-up problems. Then, students are shown theory material from their current objective (lesson), which includes interactive, multiple-choice and fill-in-the-blank exercises to test understanding. Once or twice per lesson, students are encouraged to write down important definitions or information in an offline notebook. The theory material also contains encouragement, a storyline, and clarifying questions from a variety of cartoon characters, as seen in Figure 2.2. After they complete the theory material, students are asked to answer a set of Level A (easiest) questions about the material. After each question, the student is shown the "Genie's Solution," which is the correct answer, and their own answer, whether or not they supplied a correct answer. Correct answers are congratulated by the Genie. Next, the students are given a "Notes Test" on the definitions or solutions they were previously instructed to note. These details were found in my own exploration of Reasoning Mind. If the student is ahead of schedule on their objectives, they will be given harder problems after the A Level Problems, which are called B Level and C Level Problems (Randall, 2011).

In the teacher interface, the teacher has control over many of the student account settings, such as which buildings the students can enter and when, what mathematical content the student sees, and whether remedial work is assigned. The teacher can also see summaries of student achievements. As the students work, the teacher moves around the classroom answering student questions. When some students are ahead in their work, the teacher might assign these students the role of "genie helper" to go around the classroom and help other students who have questions. The RM teachers are also encouraged to organize small group discussions based on content with which a few students are struggling. Lastly, the teachers can reward and encourage friendly competition between students based on the points and reward system built into the program (Reasoning Mind, 2011).

Reasoning Mind terms the different portions of student work "blocks." Students see Theory blocks and Problem blocks, which are identified by difficulty. At the end of the Theory block and the end of the Level A Problem block, student answers are scored to see whether the student should advance to the next objective. If a student fails the Level A Problem block, the student is sent back to the beginning of the Theory block. If a student fails the Theory Block twice or the Theory block and the Level A Problem block, then the student is sent to a Diagnostic block which tests whether the student is proficient in the material which has been deemed a prerequisite for that objective. If gaps are detected, the student is sent back to redo a previous objective. If no misconceptions in the student's knowledge are detected, the student is sent directly to the next objective. In RM's grading rubric, 50% or above is considered passing for the Theory block and 60% is passing for the Problem block. When a student completes the same block twice, the second score for the block is a "Meta Score." This means that a problem is considered correct if the student got the correct answer *either* of the times they saw that problem type (Randall, 2011).

Several advantages of Reasoning Mind are visible in its implementation of a computer-delivered curriculum, described above. First, the students are able to work at their own pace. Thus, advanced students can see new material, while students who need more time can read through the material in more detail. Second, the teacher is able to give one-on-one attention to student questions. This kind of attention is usually not available in a traditional classroom. Third, because teachers are given a summary of student progress, they are easily able to see how the students are progress-ing through the material and with what success rate. Fourth, each student is assigned individual homework which reinforces what they learned that day (Reasoning Mind, 2011).

2.2 Classroom Use Data

Given the regard for CBL's individualized pacing (Waxman and Houston, 2008), I wanted to investigate whether trends in student progress through the curriculum were discernible in data from student use of RM. I sought describable patterns in student progress through Reasoning Mind's curriculum and hoped to make a visual representation of typical student paths which indicated time spent on objectives. For example, I hypothesized a correlation between the amount of time spent by a student on an objective and his or her score on that objective. For these reasons, I asked Reasoning Mind if they could provide data that might address these needs.

Reasoning Mind keeps detailed data on all of the students working on their system on a problem-by-problem basis as well as by objective (lesson). RM provided a data set which includes data from five classrooms and 117 students total. These data are from a supplementary application of RM in fourth grade classrooms from the 2010–2011 school year, and according to RM represent a typical group of students, who had logged several hours on the system. Other than this selection process, the data were raw (Randall, 2011).

2.2.1 Data Description

The complete data set compiled in a spreadsheet (not shown) contains an entry for each objective completed by each student. Each entry has several identifiers including the student's ID number, the teacher's ID number, the class's ID number, the objective's title, and MyIndex number, a unique identifying number given to each objective. Next, the entry lists the objective's status (passed, diagnosed, or failed), the times the student first saw and last saw the objective, the total time the student spent viewing theory, in hours, and the total time spent on problem blocks, in hours. Following this, the entry lists the start time, end time, and percent of questions correct for the first time the student saw the theory, the first time the student saw A level problems, the second time the student saw the theory block (if applicable), and the second time the student saw A level problems (if applicable). Then, the table shows the start and end times for B and C level

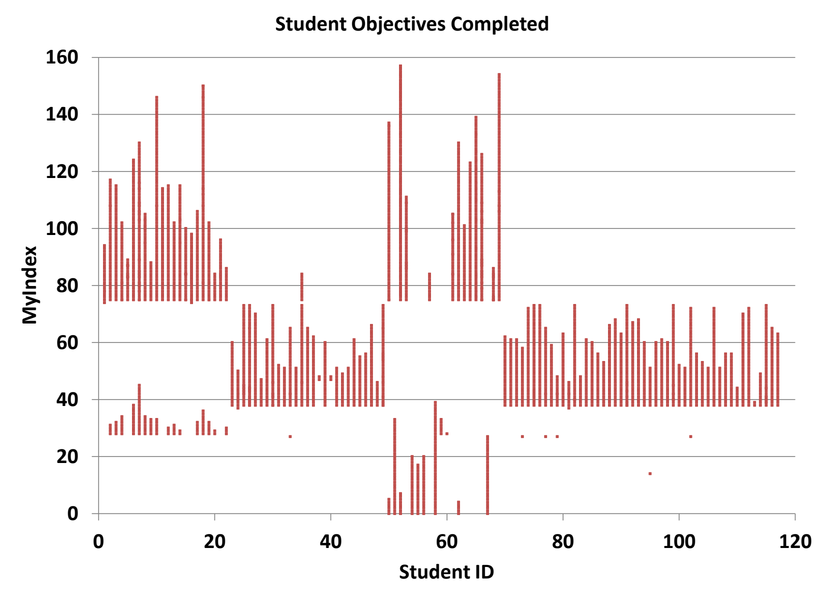

Figure 2.3 Objectives completed by each student are shown as a stacked bar graph. MyIndex is an identifier for each objective.

problems, if applicable. Finally the percent of A, B, and C level problems correct overall are given. If an objective is completed more than once by a student, each instance has its own entry in the data table.

2.2.2 Investigation

Initial graphs of the data revealed differences in usage between classes. Figure 2.3 shows the objectives completed, indicated on the y-axis, by each student shown on the x-axis. The different classes of students are grouped in vertical bands. Class 1, consisting of students 1 through 22, make up the first cluster of data on the left side of the graph. Some of these students completed some objectives numbered in the twenties, which the data table tells us was in the spring of 2010. Then in the fall of 2010, these students began using RM again at objectives numbered in the seventies. This graph gives a good overall impression of where the data came from in the cur-

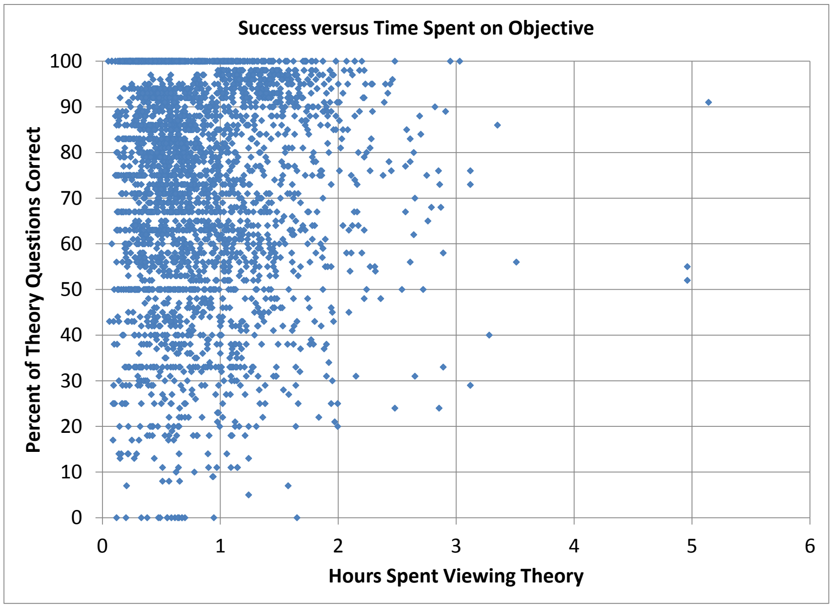

Figure 2.4 No correlation was found between the time a student spent on the theory section of an objective and their score on that objective.

riculum, what objectives were completed, and how many objectives were completed by different students.

Since the data contain several measures of elapsed time and different measures of success, I plotted different combinations of these measures. First, I graphed the hours spent looking at the Theory material versus the score on the Problem block. However, these variables are from different blocks of the objective (Theory block versus Problem block). Thus, I decided to plot times and scores from the same block, first the Theory block, and then the Problem block. As shown in Figure 2.4, no correlation was found between time spent in the Theory block and the student's score on the Theory exercises. The graph of time versus success for the Problem block did not show any correlation, either.

To understand the range of student profiles in the data, I created two new spreadsheet representations. Summary statistics for each student recorded the total number of objectives completed, total time on the system,

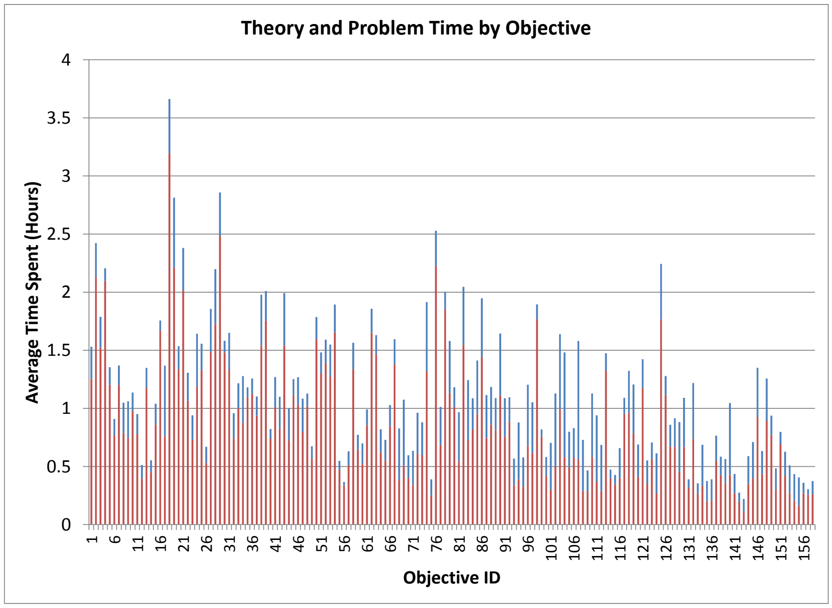

Figure 2.5 The blue bar represents the average time spent on the Problem block for each objective and the red bar is the average time spent on the Theory block. The total height of the bar is the total time spent.

on Theory blocks, and on Problem blocks, average time spent on Theory blocks and Problem blocks per objective, percent of objectives passed, and percent of total time spent on Theory. Similarly, to understand the differences among the objectives, I calculated the number of students who completed each objective, the average time spent total, on Theory, and on Problems, and the proportion of time spent on Theory versus Problems for each objective. More graphical representations, described below, illustrated these two groups of data.

Figure 2.5 shows the average time spent on objectives, partitioned into Theory block time and Problem block time. On all objectives, students spent more time on Theory than on Problems. There is a wide range of times spend on objectives from less than half an hour to over three and a half hours. Thus, outliers based on excessive time spent should not be determined only by total time spent on an objective, but in comparison to other students on that objective. A similar plot was made of the average time spent by each student total, and in Theory and Problems. No trends were observed in this representation of the data.

This reorganization and summary of the data revealed some outlying students and data points. In order to work with data from a group of standard students, several students' data were removed from the set. Four students, with ID numbers 38, 40, 60, and 113, only completed one or two objectives, so these data points were removed. Additionally, Student 52 completed 143 objectives, far more than any other student, so all of these objectives were removed. Seven students' data were removed based on a long amount of time spent on objectives. Students who spent more than three standard deviations more than the average time for each objective were considered "over time." Each student's objective time was calculated by averaging the times for each instance of viewing the theory block for an objective; students might see the theory once or twice, depending on failures of that objective. Any student with two more more objectives "over time" were removed completely from the data set. These were Students 1, 9, 16, 26, 90, 98, and 107. Finally, some students had data from objectives that they completed either before fall, 2010, or after spring, 2011. Any objectives completed outside the school year in question were removed. Note that not all of those students' data were removed, only the objectives outside of the specified time frame.

Figure 2.6 shows the remaining data, plotted over time. Each point represents when a student, indicated on the y-axis, started a new objective. Four horizontal bands can be distinguished; these correspond to the four different teachers' students. Teachers 2 and 4 started working with RM earlier in the school year than Teachers 1 and 3. Also, Teacher 4's students, seen in the topmost band, had a very high density of objectives started in the last month of class. Winter break at the end of December and beginning of January is also clearly visible on this graph as a blank vertical band.

I hoped to use these data to visualize the paths that the students took through the program, to show how long each student spent on each objective before moving on to a new objective. Preliminary attempts at this visual representation plotted the order in which the student completed objectives. However, these plots did not incorporate time dependence along the path. Students in the same classes completed the assigned objectives unless they were diagnosed or failed an objective and were sent back. For the most part, these graphs produced very similar-looking and highly overlapping paths for students in the same class. Time dependence was necessary to distinguish meaningful trends in student use of RM.

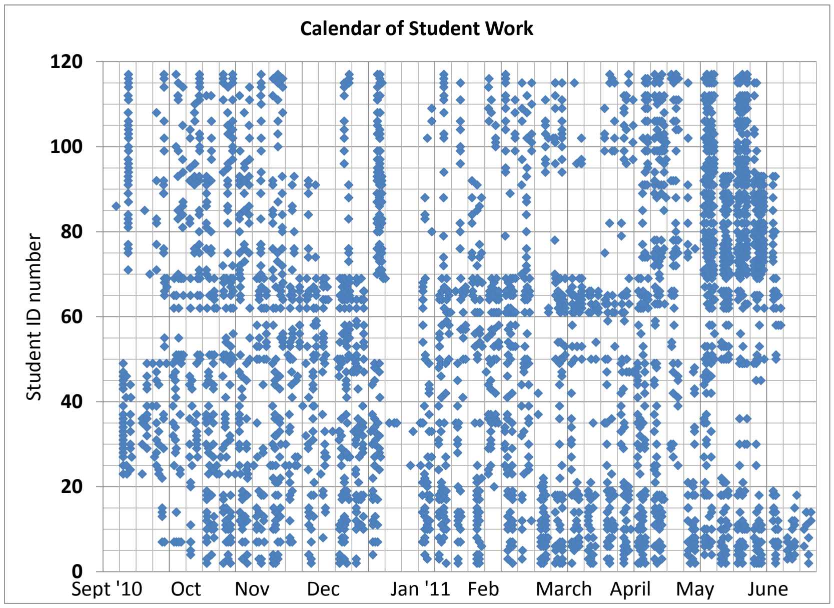

Figure 2.6 Vertical grid lines mark Mondays.

In order to incorporate time dependence, the objective start times were collected in a pivot table. In this case, for each student–objective pair, the table recorded the time the objective was started. Here, the pivot table uses time as the dependent variable, so the resulting plot, seen in Figure 2.7, is the desired plot reflected across the line $y = x$. Thus, the resulting plot is not the desired plot. Several other pivot tables were constructed. For each student–day pair, another table recorded the objective started that day, if any. Due to the gaps in this table, the paths were not connected, making it difficult to track individual students.

Significant time was dedicated to investigating Reasoning Mind's data, however no meaningful correlations were found, and path plots were unsatisfactory. From this investigation, we can see that many of the students are in fact seeing the exact same objectives as their peers. The order in which objectives are presented to students does not vary, but the speed at which student progress does.

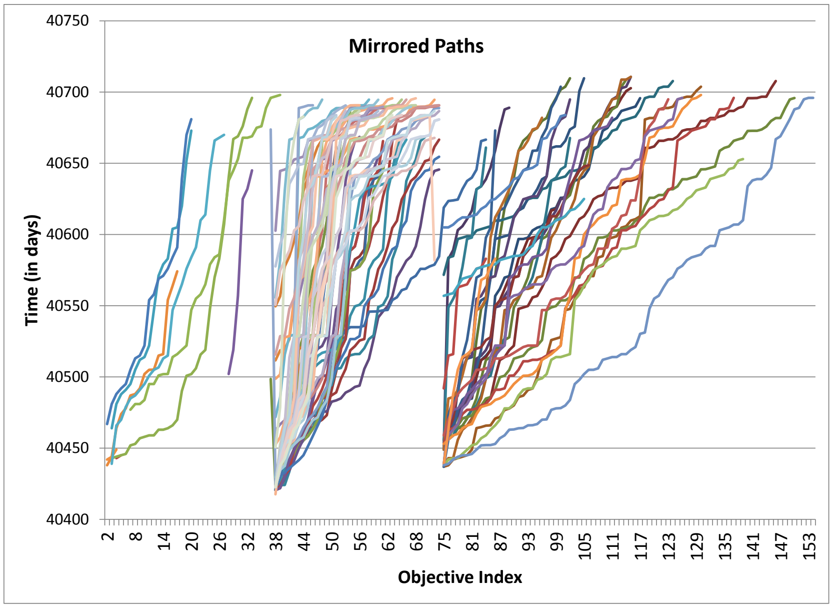

Figure 2.7 Time is measured from January 1, 1900.

2.3 Idealized Data

Despite the shortcomings of the above attempts, characterizing the paths that students follow through the Reasoning Mind curriculum would be a valuable exercise to assess the amount of differentiation afforded classrooms by Reasoning Mind. Given more time, additional data, and controlled data collection, identifying these paths would be possible. Such an analysis would allow Reasoning Mind teachers to better understand how their students are using the curriculum. I encountered several problems with this data set which should be remedied given a desire to answer these types of questions. First, it is impossible to know what the students have learned in their regular classroom and how this might affect their success in the Reasoning Mind program because these data are from a supplementary application of Reasoning Mind. Second, it was very difficult to represent the data in a chart which would easily translate to a usable plot.

The ideal data set for this investigation would have the following properties. Students should use Reasoning Mind as their core mathematics curriculum, daily, for 45 minutes to an hour. Students should complete at least 150 days of work on the system, over one school year. Approximately fifty students should be included in the study to provide a wide enough variety in learning styles to reveal any trends. Any more than this would overwhelm a plot.

The same data collection technique could be used if the data were manipulated into a more usable format. For each student, elapsed time should include only the time the student was on the system. At time zero, they should begin their first objective, and when they log off the system, time should stop elapsing until they log on again. All time stamps should be measured in relation to total time logged onto the system. This way it would be easier to compare student progress. We could easily answer, "What objective is each student on after he or she has already spent 10 hours in guided study?" Relative elapsed time is more useful than absolute elapsed time, because absolute elapsed time says nothing about how much a student has used the Reasoning Mind program. Additionally, since we know that not all objectives take the same amount of time, we would normalize the objective identification numbers to be an indicator of the average elapsed time expected to the start of that objective.

This measure of time and rescaling of objectives would allow "path plots" to be made easily, with scaled objective graphed versus elapsed time. The average student would fall along the $y = x$ line. Quick workers would advance through objectives more rapidly and have a steeper overall slope in their path. However, I do not expect these paths to be linear. Sections of a student's plot with less steep slopes would indicate objectives which took the student relatively longer than others to complete. Perhaps as students gain experience with RM, their pace through the curriculum will increase. Maybe students who at first rush and do poorly learn to slow down and read the Theory material more thoroughly. We cannot know what trends these plots would show, if any at all. However, this more targeted data collection scheme would allow for a more reliable implementation of plotting student paths to find trends in student progress through Reasoning Mind.

2.4 Level B and C Problems

Based on my work with the data set from Reasoning Mind, I saw that the students were not actually completing very many Level B and C problems. Out of 3531 objectives completed by 117 students, B level problems were completed only 17.2% of the time, while C level problems were only completed 15.6% of the time.

In order to collect a more quantitative view of the types of questions students are asked to complete within an objective during guided study, I aggregated data on the tasks students complete. I have analyzed seven objectives from the beginning of the grade four material. Any time a student was asked to provide an answer to a prompt on the screen, I classified it as an "speed game," "attention grabber/exercise," "Level A, B, or C Problem," or "Notes Test." These categorizations are defined as follows:

Speed game Speed games are labeled and include a series of six to ten questions which are meant to be answered as quickly as possible. The student races to answer these questions before the timer runs out and earns more points for answering them quickly. These are presented before an objective to test prerequisite knowledge, between subsections of an objective, and at the end of the objective.

Attention grabber/exercise I made up the label "attention grabber" (AG) for any task which is incorporated into the explanation of the curriculum and seems to be designed to make sure the student is paying attention to and reading the material being presented to them. These tasks can ask students to reproduce the steps of an example which was just shown or test a vocabulary word which was recently defined. They are very similar to exercises, but exercises are labeled as such. Exercises can include several blanks to fill in, but are always counted as one exercise. Since these two types of problems are indistinguishable except by label, they are counted in the same category.

Level A, B, or C Problem Level A, B, and C problems are also labeled within the program and are usually presented throughout theory material and before speed games.

Notes Test Notes Tests consist of several problems and specifically ask students to use the notes they took throughout the lesson to answer questions. Students are instructed periodically to "write this down" in an offline notebook. Notes Tests are given near the end of the objective.

All of the tasks include fill-in-the-blank and multiple-choice type questions. All except speed games also include matching- or categorization-type questions. A matching-type question asks a student to match each

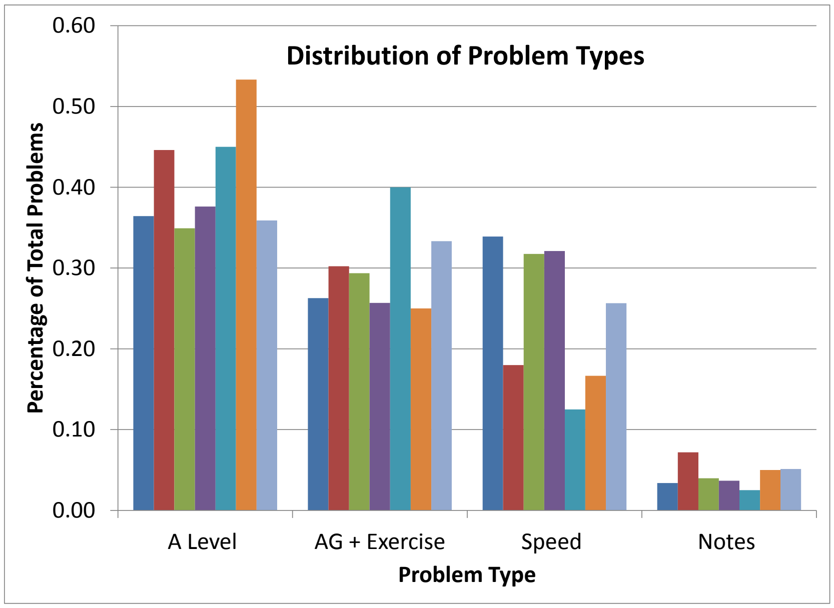

Figure 2.8 The distribution of problems from seven objectives shows that the majority of all tasks are Level A problems, while notes tests make up less than ten percent of students' work.

item in one category with another in a second category based on a quality. A categorization-type problem asks a student to choose only those items which fit into a given category.

Objectives vary in length; these seven objectives asked me to complete between 39 and 139 tasks. The majority of problems in these objectives were Level A problems. A complete summary of the problem types can be seen in Figure 2.8. Note that the percentages in Figure 2.8 will likely change depending on the student who is using the curriculum, but are a good representation of what the student is being asked to do, overall. Only one objective presented me with B or C level problems, and this was a single B level problem at the very end of objective 4.

Reasoning Mind reported that they had noticed similar trends. They believed this was happening because students were not spending as much time on the system as the system requires. Thus, the system deemed that the student needed to catch up to the schedule and skipped these tougher problems. In order to counteract this problem, Reasoning Mind introduced the Wall of Mastery building. Once a student completes a certain lesson in Guided Study, more bonus problems become available in the Wall of Mastery building, including B and C level problems. Students are encouraged to complete all of these problems of increased difficulty (Kostyuk, 2012). The Wall of Mastery serves as a visual representation of students' progress in the system and allows them to see the goal of C level problems. Additionally, this building remedies the problem of the system having the students skip harder problems by providing students access to these problems directly.

As a measure of the influence the Wall of Mastery has on children's access to nonroutine problems, I investigated the number of problems available through this building by objective and by level. According to a survey of eight objectives, there are anywhere from one to nine supplementary problems per objective per level. Each objective has somewhere between five and twenty supplementary problems. On average, there are 3.3 additional problems per objective per level accessible through the Wall of Mastery.

Thus, we see that although level B and C problems exist, students' main exposure to them is through the Wall of Mastery and not through Guided Study.

Chapter 3

Understanding the Russian Educational System

Reasoning Mind claims to be based on Russian pedagogical ideas. Isolating specifically Russian aspects of a curriculum proves problematic for several reasons. First, Russia is a large country with a varied history. National practices are not implemented uniformly across space or time. Russian education has changed significantly over the last one hundred years, with the establishment and dissolution of the Soviet Union. Many people still associate Soviet ideas of education with Russia, despite recent reforms. Second, Russian education is not isolated from outside ideas. While many of its ideas come from within the country, Russia also draws on European trends in education. Finally, curricula present an incomplete picture of pedagogy. I have not seen either a Reasoning Mind nor a Russian classroom; I can only try to understand Russian aspects of teaching through the idealized version represented in the curricula and what I have learned second hand.

I collected a wide variety of sources to investigate Russian aspects of mathematics education. First, I interviewed Ann Esin, a physics professor at Harvey Mudd College. Professor Esin was raised in Russia and attended Russian schools through tenth grade. Her children attend American schools and she uses this experience as a basis for comparing the two educational systems. The interview included a discussion of both pedagogical and curricular differences between American and Russian schools. Additionally, I investigated several individual accounts regarding teaching or learning in both American and Russian schools. Finally, I read two texts used by RM as a basis for their curriculum, *Russian Mathematics Education: History and World Significance* and *Programs and Practices* by Alexander

Karp and Bruce R. Vogeli. Victor Kostyuk and Alex Randall, two engineers at Reasoning Mind, emphasized the importance of Karp and Vogeli's two volume work on the RM curriculum and philosophy. Victor first recommended these books because they give a thorough history of the math curricula that are currently used in Russia, and also a summary of the source text Reasoning Mind relies on most heavily, written by Moro (Kostyuk, 2012). Alex Randall reported that virtually all the employees of RM are familiar with the contents of Karp and Vogeli (Randall, 2011).

3.1 Soviet Legacy

Russian education, especially mathematics and science education, enjoy residual effects of the the Soviet Union's reputation as an effective school system. During the Cold War era, the Soviet school system was known for "eradicating illiteracy, expanding the network of educational institutions, training a work force, forming the scientific and technical potential of the country, developing national/ethnic educational systems, and ensuring that education was accessible" (Borisenkov, 2007). Soviet education also included a large emphasis on teaching morals, collectivism, and the importance of labor (Tudge, 1991). One of the reasons this system is viewed so favorably is because of its emphasis on making education available to everyone in the country, and its dedication to the quality of its schools.

The Soviet Union had a reputation of producing very talented scholars in the fields of mathematics and science. "By the early 1960s, for example, the level of training of the graduates of Soviet secondary schools was one of the highest in the world in regards to the natural science cycle and mathematics" (Borisenkov, 2007). Despite the dissolution of the Soviet Union in 1991, its legacy lives on as many still associate Russian education with Soviet education. By invoking this association, Reasoning Mind lends legitimacy to its program and implies successes comparable to those of the Soviet education system.

3.2 Russian Attitudes Toward Learning

Since projects with popular support are more likely to flourish, society's attitude toward learning can influence the success of a an educational system. High expectations for students, intensive teacher training programs and greater government involvement in educational standards indicate positive attitudes toward learning in society.

Esin described Russian mathematics teachers as having higher expectations of students than American education (Esin, 2011). This attitude is also reflected in Andrei Toom's description of his American students. Toom wrote from his perspective as a Russian university professor teaching at an American college. He reported that American students do not want to learn for the sake of learning; they only want to learn the bare minimum required to graduate. He laments his inability to challenge student thinking, which comes from the students' expectation that the professor not go beyond what is written on the syllabus, or what is "required" of them. Toom claims that this is an American attitude, very unlike the reverence given to learning in Russia (Toom, 1993). His American students were used to being held to a lower standard and performed to that standard.

In Russia, teachers choose their profession earlier than American teachers. They are taught very specifically about pedagogy and content. Additionally, Russian mathematics teachers are expected to know the curricula for students of all ages. Because of this broad basis of knowledge, they can build a strong foundation for their students to help them in future years. In Russian society, teachers are highly respected because they are held to these stricter standards (Esin, 2011). According to Esin, if a teacher tells a parent that a student is performing poorly in class, the parent does not complain that the teacher is not doing his or her job, as is common in the United States. The teacher's expertise is respected above the parent's opinion. In addition to having higher standards for teachers, Russia has higher standards for what material is appropriate to teach when. In particular, Russian students learn topics earlier than American students (Esin, 2011).

As a country, Russia has a long history of universities which specifically develop teaching methodologies. All of the materials necessary to teach a class, such as workbooks, textbooks, and lesson plans are developed together by a group of specialists including mathematicians and teachers. These bundled materials, called "series," undergo field testing before they are approved by the government. The Russian curriculum is nationalized; only seven different text books have been approved for use by the government (Konovalova, 2011). Karp and Vogeli state that "there are 15 curriculum 'series' or 'complexes,' as they are called, in Russia in mathematics for the elementary school, evaluated and included in the federal register of textbooks recommended by the [Russian Federation] Ministry of Education and Sciences for use in Russian schools" (Karp and Vogeli, 2011). Russian curricula are thus highly standardized.

Higher student expectations, more specific teacher training and strict government regulation of educational materials suggest that Russian education may be superior to other systems. These reasons provide a backdrop for the rest of our investigation; we aim to find more specific details about the classroom practices and curriculum differences that distinguish Russian education from other countries' systems.

3.3 School Structure

Next, we investigate the structure of the mathematics education a student in Russia might experience, both on a day-to-day level and over the course of their elementary education.

Students in Russia have 45 minute lessons and daily mandatory homework assignments. Mathematics and Russian language classes are specifically not scheduled at the beginning or end of the day because students are less attentive during these times. Unlike in American schools, there are no PA announcements during the day that might interrupt lessons. Finally, each student's homework is graded daily (Konovalova, 2011).

From first through third grade, students have the same teacher. Students learn basic addition, subtraction, multiplication and division facts, and long division. Algebra is introduced as early as third grade with students solving simple problems with variables, such as, "If $x + 3 = 10$, find x." Unlike in America, there is an emphasis on abstraction of topics early on. Students are also introduced to set theory by third grade. In fourth grade, students begin learning different subjects from separate teachers (Esin, 2011).

The esteem toward mathematics and complex problem types taught in elementary school suggest national recognition of the importance of mathematics education. Russian appreciation for learning supports RM's premise that the Russian educational system should be emulated.

3.4 Russian Teaching Characteristics in RM

Through my research, I have formed a list of pedagogical characteristics, split into classroom practices and aspects of curriculum, that are often cited as Russian. I define a Russian characteristic as any technique or idea which is used in Russian classrooms. I have collected characteristics which originated in many different places and times, but which have been identified recently as part of the Russian educational experience. Classroom practices are activities that are expected from the students and teachers and in their interactions. Specifically, these include behaviors that teachers cultivate in students. Curriculum aspects can generally be described as common problem types and techniques used by the authors of the curriculum to impart knowledge or query students, but also types of thinking or even actions that are asked of the students specifically by the curriculum. While both of these categories include demands on the students, coming from two angles, teacher and text, I find this distinction important to make for the following reason. As an American student, I am able to directly view the curriculum with which students are working. However, the proceedings of Russian classrooms that I have studied are all secondhand. Thus, although they are included here, it should be kept in mind that it is harder to understand how these classroom practices are actually implemented. Note that a citation of Karp and Vogeli indicates that at least three out of fifteen series used in Russia include this aspect.

Additionally, it important to keep in mind that the characteristics I have chosen reflect my understanding of trends. These characteristics can no doubt be found in classrooms and curricula in America and around the world. Russian classrooms do not necessarily implement all of these trends one hundred percent of the time. However, I claim, based on my research, that these practices are used more consistently across Russian classrooms than in other countries' learning environments.

In order to better understand how Russian pedagogical ideas are incorporated into the Reasoning Mind system, I conducted a Skype interview with Victor Kostyuk, a Knowledge Engineer at Reasoning Mind. He provided examples in Reasoning Mind of an emphasis on mental math, nonroutine problems, and precise mathematical language. Additionally, I spent considerable time working in the RM system myself, mostly on the student interface. All of the screen shots shown are from my own time working in the system. Below, I first introduce a characteristic of a Russian classroom and subsequently discuss its implementation in RM before moving on to the next characteristic.

3.4.1 Classroom Practices

Differentiation

The Russian system of education is notoriously strict and regimented, not allowing any differentiation (Esin, 2011). Russian Leonid Illushin notes that the differentiation he observed in an English classroom "is not similar to [his] experience in Russia" (Stokoe and Illushin, 1998). Contrary to this position, Yuliya Konovalova states that there are many opportunities for differentiation; for example, problems are assigned on a student-by-student basis and math Olympiads provide supplementary work for advanced students (Konovalova, 2011).

Reasoning Mind allows for great differentiation in the classroom because each student can work at his or her own pace. Thus, students who understand the concepts can move quickly through the material, while other students who might need more time can take it. Also, it allows students to spend more time on topics that they find troublesome and move through whatever lessons they find easiest faster. The program generates homework specific to each student based on the material which that student has completed (Reasoning Mind, 2011).

Encouraging Competition

Student grades are posted in the halls of the school for all to see (Levy, 2011). This creates competition among students, with the goal of improving poor performances and rewarding successes.

RM students can interact competitively in the virtual Game Room in Reasoning Mind. Additionally, it is possible for the classroom teacher to implement a system to encourage friendly competition among students, based on the points earned in the online tasks. While it is not required by the system, it is encouraged by training given to all Reasoning Mind teachers.

Precise Mathematical Language

Mathematical vocabulary is emphasized both by the curriculum and by the teachers in the classroom. Students are encouraged to use precise mathematical language and are corrected by their teachers when it is used incorrectly (Kostyuk, 2012).

Reasoning Mind students learn to use precise mathematical language though the modeling of language by the system in problem statements and definitions. For an example, see Figure 3.1 where students learn the names of the different parts of a subtraction sentence. Students are also prompted to write down definitions of words in their notes. However, one of the limitations of RM is that it cannot easily check the validity of text solutions to problems, thus these are not incorporated. Correction of student language use is thus the responsibility of the classroom teacher.

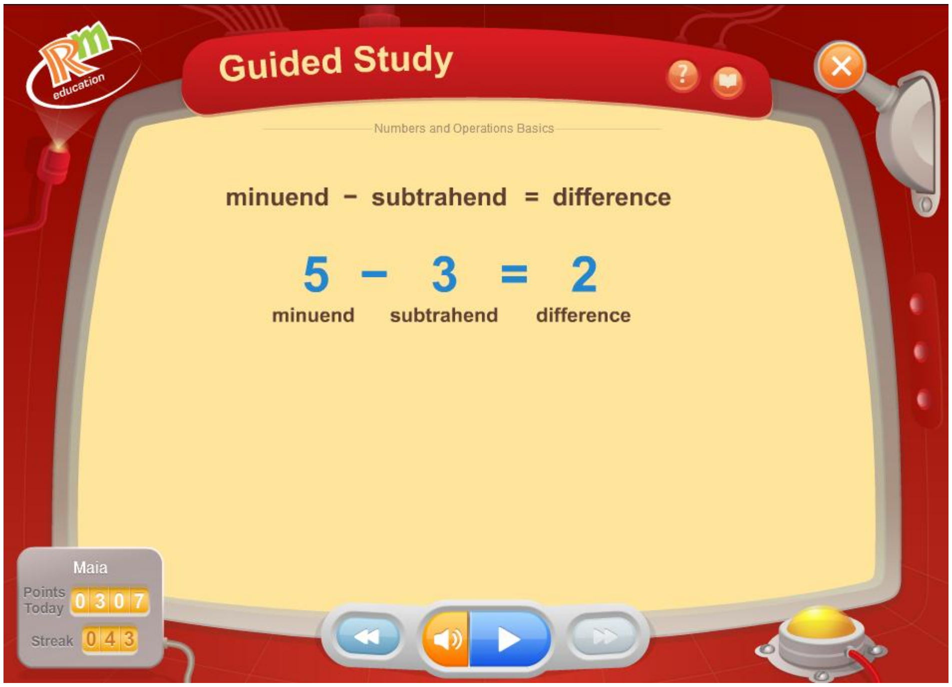

Figure 3.1 In Guided Study, students are introduced to precise mathematical language such as "minuend," "subtrahend," and "difference."

Group Work

"Many text books include group exercises, aimed at developing communication skills in children." Texts also use characters with competing viewpoints to normalize the experience of communicating diverse ideas in a group and accepting others' viewpoints (Karp and Vogeli, 2011).

In RM, there are animated characters with differing viewpoints representing the idea that group work allows students to encounter novel ideas. Additionally, student–teacher and student–student interactions are also encouraged by RM classroom teachers; the classroom techniques are reinforced by the professional development provided for the teachers by Reasoning Mind. Teachers work with students who are struggling one-on-one or in small groups. Additionally, teachers may assign students who are ahead in their work to be "genie helpers" to go around the class and assist other students with their work. In this situation, students receive some of the benefits of group work, but not all of them.

Work at the Board

Teachers frequently call students up to the front of the room to individually work problems on the board while the rest of the students watch. Then, the student must explain his or her answer and other students are encouraged to discuss whether they agree or disagree with the solution (Esin, 2011; Levy, 2011). Students must be confident in articulating and defending their solutions to problems.

Reasoning Mind currently does not include work at the board since each student is working at his or her own computer. A new version of Reasoning Mind's sixth grade program incorporates these ideas (Kostyuk, 2012). These changes are discussed in Section 4.1.

Defending Answers

At many Russian schools, student examinations consist of a student presenting the solution to a problem for a panel of teachers. Students are challenged to communicate their answers thoroughly and convincingly (Levy, 2011; Kostyuk, 2012; Esin, 2011).

On the Reasoning Mind system, students are immediately told whether their answer is correct or incorrect. Thus, they are never prompted by the system to defend an answer to the teacher or to another student.

Calculator Use

Students are encouraged in many curricula to use calculators to check their work (Karp and Vogeli, 2011). Calculators are not meant to replace mental calculations, but to let students verify the validity of their answers. Students are taught how to leverage calculators and not fall into the trap of relying on them too heavily.

As far as I know, students are not encouraged to use a calculator while using RM.

3.4.2 Curriculum

Unconventional Problems

Problems in Russian workbooks are often presented as a puzzle instead of just a computation. These questions still require mathematical thinking, but are not tedious for students. Word problems are emphasized very early and become increasingly more difficult as students gain experience (Esin, 2011).

There are three levels of problems in Reasoning Mind, levels A, B, and C. While level A problems test a basic understanding of the content of the curriculum, the level B problems require more interpretation and thought from the student and usually two or three steps. Level C problems introduce new applications of the math learned in the objective and require more logic on the part of the student rather than just computation. Students can encounter these three levels of problems while in Guided Study, or they can enter the Wall of Mastery building and see additional level A, B, and C problems. When they enter the Wall of Mastery Building, students see the screen in Figure 3.2. The objectives are listed down the left column. Check marks indicate that a student has completed the Wall of Mastery problems for those objectives and levels. An arrow means that a student has unlocked those problems but has not yet completed them. Students unlock level A problems by completing the theory material for an objective and unlock subsequent levels of problems by completing easier problems. Based on a sample of eight objectives, there are about three additional problems per objective per level on average. A more detailed description of the number of problems available via the Wall of Mastery is given in Section 2.4.

Figures 3.3, 3.4, and 3.5 show examples of level A, B, and C problems. The level A problem asks the student to identify the sum and summands in a given problem, concepts which were explicitly introduced in the Guided Study. The level B problem asks the student to fill in the blank to make the equality true, a problem which requires at least two steps of arithmetic. The level C problem gives the students numbers and mathematical symbols and asks them to make a true statement. Notice that the C level problem has multiple correct answers, and there are many ways to go about solving this problem. The level B and C problems are nonroutine problems that Reasoning Mind has made more accessible through the Wall of Mastery.

Correction of Problems

Students are presented with a math problem which has already been completed and are asked to decide whether the answer is correct or incorrect (Karp and Vogeli, 2011).

Tasks in which students correct others' problems exist in RM. Students are shown a problem and asked to decide whether it is correct or incorrect.

Figure 3.2 The screen students see when they enter the Wall of Mastery building lets them choose an objective and a level of problems on which to work.

There is no subsequent step where students must demonstrate the correct answer.

Concentric Construction

Almost all of the Russian textbooks are "structured concentrically: the students first learn the numbers 1 through 10, then the numbers up to 100, and then up to 1000 and beyond" (Karp and Vogeli, 2011). Concepts are built up sequentially beginning with a core simple idea leading to a more complex set of ideas which includes previous ideas.

Reasoning Mind definitely uses a concentric curriculum construction. This can be seen from the titles of the objectives, such as "Mental Addition and Subtraction within Twenty" and "Numbers up to 1000: Places and Reading." Skills are broken up by the numbers to which they are applied.

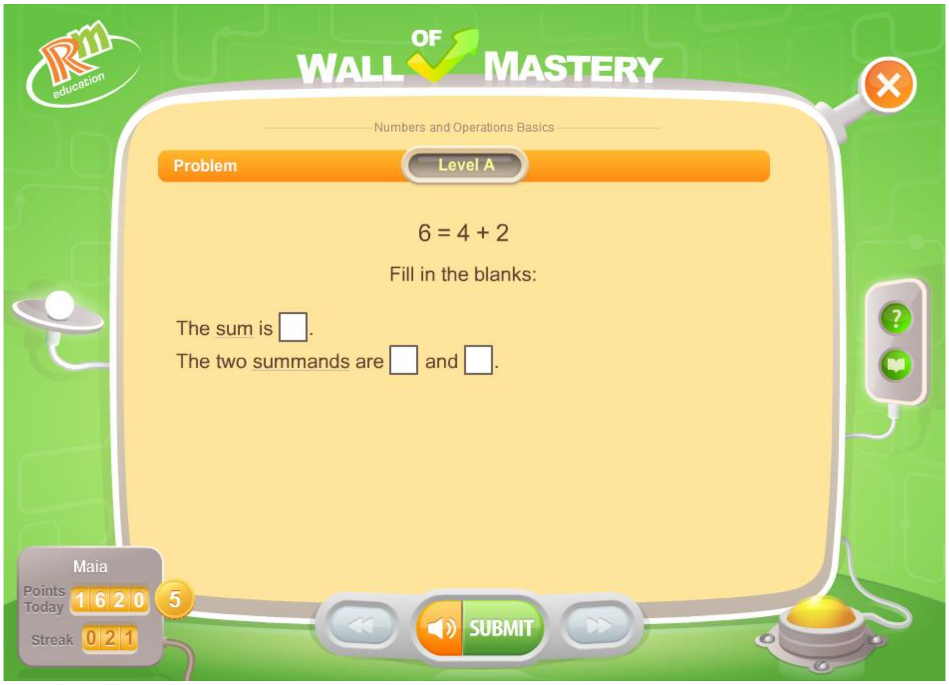

Figure 3.3 Level A problems test the material directly.

Modeling

Curricula include heavy use of mathematical modeling of situations. Modeling can include manipulatives, drawn representations, and physical models, among others. (Karp and Vogeli, 2011)

Reasoning Mind does all of its modeling virtually, as necessitated by its computer interface. There are also some virtual manipulatives, which can be moved in prescribed ways. There are advantages and disadvantages to these virtual representations. Virtual representations can be dynamic rather than static, which is an advantage when explaining topics to students. However, the student cannot always move the manipulatives in any way they want, a disadvantage over traditional manipulatives.

Mental Calculations

In most cases, students are "first [taught] oral calculations and then written calculations" (Karp and Vogeli, 2011). This suggests an emphasis on mental

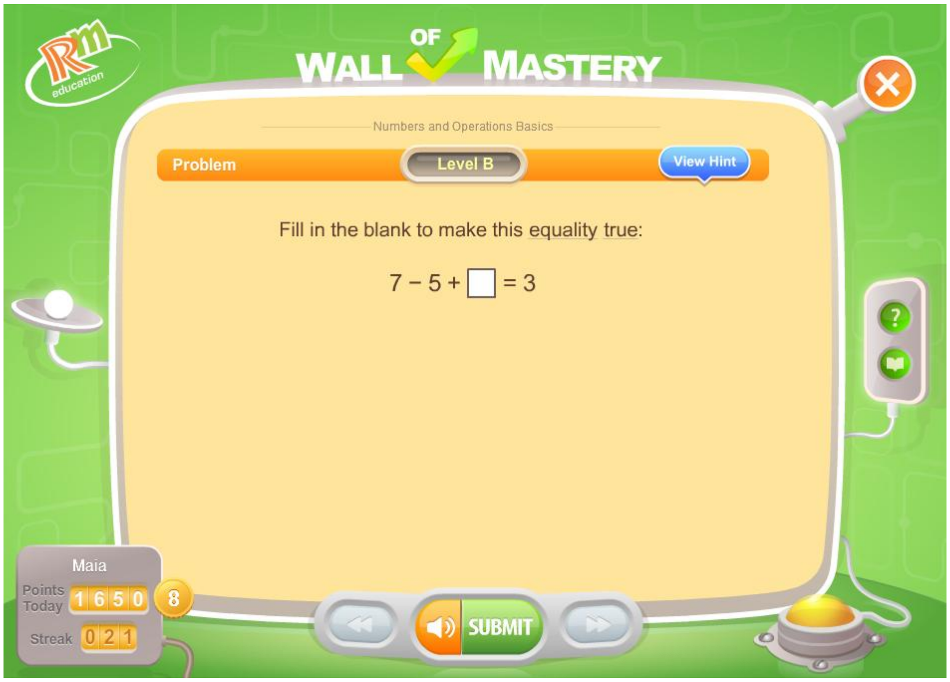

Figure 3.4 Level B problems require more than one step.

math versus pencil and paper computations.

Reasoning Mind students drill mental math facts through speed games which are incorporated into the Guided Study. These games also are presented at the start of the Guided Study and included throughout the material. Students are encouraged to use mental math and discouraged from using pencil and paper or counting on their fingers, as seen in Figure 3.6. As an incentive, students gain more points for answering questions more quickly.

There are different themes for these speed games such as "Math Robot" or "Busy Ants" but all the games have the same format. The student is asked to fill in a box with or choose the correct answer for a problem which is usually a simple arithmetic problem corresponding to the progress of the student. For example, in earlier lessons students may be presented simple addition problems, or asked to place a $>$, $<$, or $=$ sign correctly between two numbers.

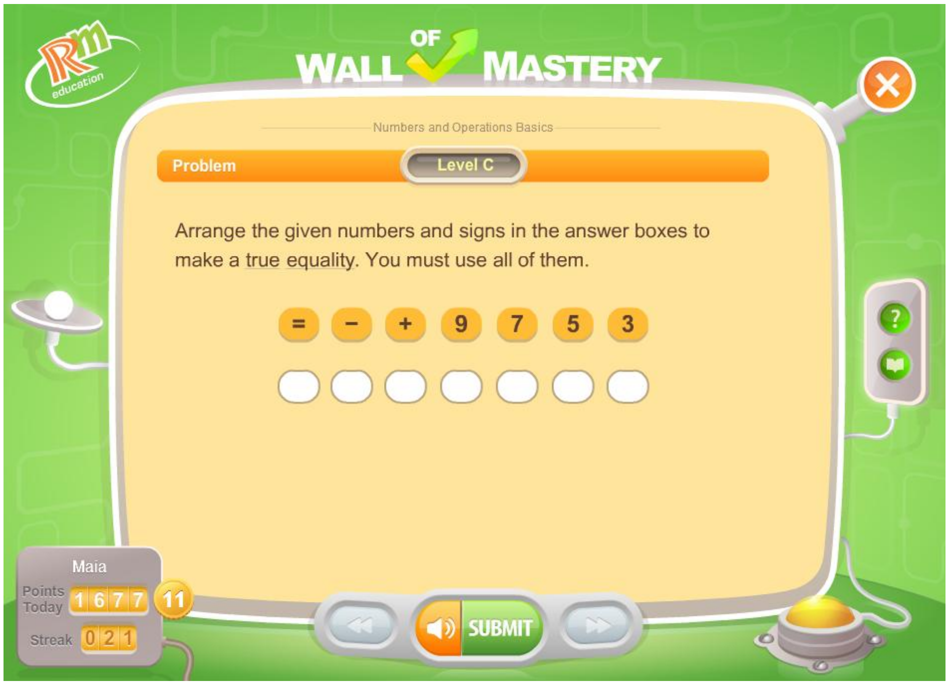

Figure 3.5 Level C problems are the most challenging and require new solution techniques and reasoning.

Incorporated Review

In the construction of the curriculum, strict attention is paid to the lesson structure. High priority is given to the incorporation of older material for review into the current lesson (Konovalova, 2011). Each lesson includes review material mixed in with new material. In this way, the students are able to practice recognizing situations in which previously learned material should be used (Esin, 2011).

Reasoning Mind does incorporate review material into the questions students are asked to complete. In particular, before starting a new objective, students are presented with problems relating to material from any previous objectives to make sure that they have the foundation they need to move on. Additionally, the Wall of Mastery encourages constant review of previously completed objectives by offering additional problems which the student can complete at any time.

Figure 3.6 Before speed games, students are reminded to use mental math instead of pencil and paper or fingers.

Creative Thinking

Students are encouraged to "find a solution strategy independently and draw their own conclusions" (Karp and Vogeli, 2011).

Due to the fact that RM is on the computer, it is difficult to encourage creative thinking or novel solution strategies. I have not seen many problems, if any, that ask students to draw their own conclusions from presented information.

Personalized Education

Students are asked whether certain problems or topics are easy or hard, interesting or boring. Problems use the word "you". Students are taught multiple solving strategies and are provided exercises with a range of difficulty (Karp and Vogeli, 2011).

Other than the differentiation inherent to the program, there is little in RM that might fall into personalized curriculum. All students are shown the same set of questions over different time periods. In the sample of objectives seen in the current work, a single solution strategy was always presented.

Holistic View of Problems

Activities require students to consider the whole problem and perhaps manipulate the task to make it easier before diving into computation (Konovalova, 2011). Students are encouraged to step back and view the problem as a whole before concerning themselves with the details.

I have not seen any evidence of this in the objectives I have studied. Students are often taught one solution strategy and then are expected to apply it immediately. They are not required to simplify a problem before completing calculations.

Chapter 4

Conclusions

Based on the above analysis, we can form some conclusions about Russian influences on Reasoning Mind.

I identified seven classroom aspects and nine curriculum trends which are typical of Russian education. Out of these sixteen total Russian characteristics, ten are implemented in Reasoning Mind (differentiation, encouraging competition, precise mathematical language, group work, unconventional problems, correction of problems, concentric construction, modeling, mental calculations, and incorporated review). Notably, six out of these ten fall under the category of aspects of the curriculum as opposed to the classroom experience. While four out of seven classroom aspects are implemented completely, six out of nine curricular trends are.

Overall, this analysis suggests that Reasoning Mind students are benefiting from many of the aspects of a Russian-style curriculum, however, they may not be having a Russian-style classroom experience. By removing the teacher from the role of direct instruction, RM is removing opportunities for the teacher to interact with all of the students at once. It is in these entire classroom situations that teacher could have students work at the board, defend their answers, learn correct calculator usage, think creatively, or view problems holistically.

4.1 Reasoning Mind's Progress

Reasoning Mind is currently working to incorporate more aspects of Russian pedagogy into their system, including remedying some gaps which I have identified above. Engineers at RM are designing a system to more quickly and accurately diagnose gaps and misconceptions in student learning. They are also working to incorporate more well-timed review of concepts into their lessons, so that students can study concepts from previous lessons when it will be most beneficial (Huhn, 2011).

Additionally, in order to implement simulated board work, RM is working on creating a virtual classroom. While the computer cannot simulate a conversation which involves the student using the system, it can represent a conversation between another student avatar and a tutor or teacher character. That way, the student still has the experience of hearing another student "work at the board" and trying to find discrepancies in that work. However, the student does not experience working at the board. This would acclimate students to the idea of trying to understand others' reasoning (Kostyuk, 2012).

4.2 Recommendations

As we have seen above, Reasoning Mind has shown success incorporating aspects of Russian pedagogy and curricula into their program. Missing aspects include encouraging students to work collaboratively and talk to each other about math. If RM's goal is to recreate the Russian learning environment for American students via their computer-based system, I encourage them to rethink the possibility of this happening. I believe that no online learning environment will ever completely mimic the Russian classroom. Too many Russian aspects, such as students defending their answers and participating in competition to motivate their learning, simply cannot happen online. RM has already shown a commitment to making their program part of a complete classroom experience. I encourage them to continue the process of thinking about how their system can be used as a tool in the classroom to foster real life interactions between students and teachers. If Reasoning Mind thinks about their product as part of a larger learning environment as opposed to a self-contained curriculum, then RM users will benefit from a more Russian classroom experience along with their exposure to Russian curricula. Reasoning Mind will never be able to recreate the Russian learning environment completely, but they can facilitate offline experiences that are integral to such experiences.

Note that my experience with how the RM program works is completely through the system. Thus, I am basing the classroom experience only on what I have learned about the training given to RM teachers. As I understand, RM teachers go through extensive training in order to use RM in their classrooms, and there they are taught about some of these classroom aspects discussed above. However, I propose that RM make these aspects more obvious in the system itself. For example, there should be tasks online which require offline collaboration by students. RM can prompt these classroom interactions without actually staging them directly. As a growing enterprise, Reasoning Mind will not always be able to provide training to all of its teachers. Thus, these classroom aspects must be incorporated into the system, so that RM can be used as a tool by any classroom teacher.

4.3 Future Work

The current study was hindered by the lack of seeing Reasoning Mind in action in a classroom. Future work on determining the extent to which RM is implementing a Russian experience should include visiting an RM classroom and assessing the real life implementations.

Additionally, future work could include data collection and analysis as described in Section 2.3. Such an analysis would be able to quantify differentiation in RM and allow teachers to better understand their students' interaction with the program.

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