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We live in a society and culture that has learned to fear mathematics. Having a mathematical brain is considered an oddity and it is assumed that anyone who understands math must be really smart. Yet, the skills needed to demonstrate awe-inspiring mathematical ability are quite limited. Basic arithmetic skills allow restaurant patrons to calculate a 15% tip by adding the GST and PST together. Standard wholistic addition and subtraction aids in limiting the weight of loose change in one's pocket by encouraging payment of $10.03 for a bill of $9.98. (I.e. deciding to trade one bill and three coins for one coin instead of one bill for two coins.) Determining whether the larger cereal box is actually a better deal requires simple division to compare unit value. The background math skills for these tasks are learned in primary grades and should be readily available to most adults. However, a lack of contextual practice hampers many people's ability to perform these tasks.

Despite the many years of required education a large swath of the population lives without proper mathematical comprehension. We have even begun to depend on this poor numeracy level. A common marketing technique involves offering interest-free delayed payment for services or products rendered now. This approach appeals to a large portion of the western population who have learned to prize the accumulation of commercial goods and frequently live beyond their means. However, the success of this strategy is dependent upon poor numerical awareness within the consumer cohort.

Consider a situation in which a $1000 couch is purchased "interest-free," with four monthly payments of $250 beginning one month after the purchase date and a one-time administrative fee of only $50. (Although taxes usually apply they must generally be paid up-front and are therefore irrelevant to the following calculations.) At first glance, interest-free promotions may seem appealing and their frequency suggests that many consumers are correspondingly fooled. For a $1000 purchase, the $50 administrative charge is equivalent to a one-time 5% interest charge. In order to reach a total payment value of $1050 over four months in a standard interest arrangement you would be paying interest at an annual rate of 24%, compounded monthly. This, so called, savings promotion actually costs more than the standard credit card! In fact, in order to bring the $50 administrative charge to an interest level below current prime levels the consumer would need to purchase $5000 worth of furniture. The math skills needed to confirm these calculations are limited to basic addition, subtraction and multiplication and can be performed rapidly with a calculator. However, in order to begin the calculations, the consumer needs to have an internal numerical awareness and comprehension that prompts them towards a realization that the "interest-free" proposal might not be accurate.

The Ontario education system requires students to participate in math classes through to grade 11. Yet, students frequently fail to encounter math in context and rarely build full mathematical competence, thus becoming part of the consumer market for the interest-free promotion already discussed. The Chinese Room thought experiment developed by John Searle, explores problems with learning void of context.

This paper will introduce the Chinese Room by presenting Searle's arguments and creating a scenario for the reader to ponder. Then, some standard information about math education will be explored both with approaches that rely on the learning processes of the Chinese Room and others that contradict it. This intersection between Searle's Chinese Room and math education illustrates problems with traditional approaches to math education and challenges some of Searle's conclusions regarding the Chinese Room.

The Chinese Room

Searle's Arguments

John Searle presented the following argument, commonly referred to as the Chinese Room argument or thought experiment, as an argument against strong artificial intelligence. Searle defines strong artificial intelligence as "the claim that the appropriately programmed computer literally has cognitive states and that the programs thereby explain human cognition" (Searle, 1980). Searle used his Chinese Room thought experiment specifically in the context of computer intelligence. However, if the argument proves to be valid, then it details learning processes, or lack thereof, in a wide range of circumstances.

In the Chinese Room thought experiment, a person, with no prior knowledge of Chinese, is placed inside a room. This room contains the tools necessary to receive Chinese character inputs and to respond with the appropriate Chinese character outputs. This person is fed a story, in Chinese, and then asked questions about it (i.e.

receives input). Information in the rule books found in the room allows her (or him) to look up the received input and learn which Chinese answers to send back. Ultimately, the person in the room manages to pass a Turing test for communication but, Searle argues that this person would have no actual Chinese language comprehension. The person in the Chinese Room would simply be following a set of formal rules regarding which outputs belong with received inputs.

In essence, the person is locked inside a room full of books that explain what to do with every possible input. The books are written in English and are easily understood by the person using them to look up responses. This search and retrieve approach is one commonly used by computers and has produced results that appear to be successful. However, it could be compared to following an instruction book to program an old VCR. (Note: I have specifically chosen to indicate an old VCR since modern models are designed for usability.) You looked up which step followed the last until the book indicated that you were done and you hoped that you had followed all steps accurately. You were left to assume that the book knew what it was doing because you received no external verification of success or failure. We will return to this example later because it presents problems within the Chinese Room argument. However, it also highlights the claim that computers are merely engaged in a complex rule abiding process rather than cognition.

Searle (1980) indicates that he has presented the Chinese Room thought experiment to several artificial intelligence workers and expresses surprise that their responses varied. I would argue that any field is served by diverse approaches and that the broad range of responses has added depth to Searle's argument. In response to one form of criticism he extends his argument to cover situations in which the entire system of reading, examining the rule book, making notes and providing answers is said to comprehend Chinese. In response to this view, Searle (1980) counters that the individual inside the Chinese Room could, eventually, memorize the rules and become confident about the proper output to follow each received input but that this formal symbol manipulation remains void of meaning. If asked questions about restaurants in English, the person would answer questions with an understanding that they were discussing hamburgers. However, when responding to Chinese questions the responses would simply consist of knowledge that character X follows character Y.

Can you Learn?

Imagine yourself locked in a similar room. There are boxes full of Chinese symbols, which you cannot read nor even reliably identify as Chinese. There is a rule book written in English which can be used to correlate incoming questions with the appropriate symbols from the boxes. Or, more realistically, there is a set of many rule books, written in any language that you understand, which will help you find the appropriate Chinese answer for each question. In other words, by reading the rule books you will be able to fish the correct symbols out of the boxes and send them out of the room. Through these actions you will be answering questions in much the same way that a computer looks up information from its pre-programming and answers questions. Can you learn Chinese from this environment?

What if, instead of being asked to answer questions in Chinese you were asked to complete a complicated mathematical calculation? The question comes in, you look up the procedure in your rule books and follow the steps precisely until you reach an answer which is then returned to the asker. You might even be asked to show your solution in which case, you can send out the steps from all of the precisely followed rules. Have you learned to comprehend mathematics?

To the recipient of your mathematical solution you may appear to have understood the process and to know how to solve problems of a similar ilk. However, in reality, all you know how to do is follow the given set of rules and without the rule book you would be unable to resolve additional problems. It is the claim of this paper that standard math education leaves most students in the same position as the person in the Chinese Room. Many students learn, and eventually memorize, the rules of mathematics without developing comprehension of the true meaning of their calculations. The application of Searle's argument, that learning rules does not equal comprehension of meaning, to the way in which people learn mathematics will be explored in the following section.

Math Education

Curriculum

The Ontario Ministry of Education's elementary school curriculum (2005) states that our "society require[s] individuals who are able to think critically about complex issues, analyse and adapt to new situations, solve problems of various kinds, and communicate their thinking effectively." However, despite this lofty goal, teaching students to think laterally and integrate mathematics into their comprehension of the world remains elusive.

While it is becoming less common to hear calls for a return to the three R's of reading, writing and arithmetic there are still many who believe that our current challenges with math education are due to a failure to enforce basic rule learning. Bill Quirk (2005) argues that math is a stable construction that exists only in the human mind and that should be taught as facts and skills to be mastered. He states that "math thinking…depends on remembered math facts and remembered math skills" (Quirk, 2005). In other words, students need to read and memorize the rule books associated with mathematical thinking.

The preface to an early Ontario math textbook indicates that it has omitted the rules common in ordinary textbooks (Canadian Ministry of Agriculture, 1887). It argues that this decision has been made because students require oral presentation with variation of expression and vocal emphasis in order to see every solution developed step by step. Yet, if the pages are turned and the text is scanned, every chapter begins with a listing of rules, there are addition and multiplication tables and lists of repetitive problems to ensure enough practice for memorization to occur. Plus, it is not the use of vocal inflection, or the reading of bad handwriting, that leads a student to understand their actions. Understanding is a much more elusive experience than the basic act of listening.

Despite the stated goal of developing critical thinkers, the current curriculum also focuses on math facts and skills rather than conceptual exposure. Highlights for each grade outline "required skills and knowledge in detail and provide information about the way in which students are expected to demonstrate their learning " (The Ontario Curriculum Grades 1-8, 2005). The Grade 1 highlights begin with:

> **Number Sense and Numeration:** representing and ordering whole numbers to 50; establishing the conservation of number; representing money amounts to 20¢; decomposing and composing numbers to 20; establishing a one-to-one correspondence when counting the elements in a set; counting by 1's, 2's, 5's, and 10's; adding and subtracting numbers to 20.
>
> (The Ontario Curriculum Grades 1-8, 2005, p. 31)

All of these listed skills are necessary for the performance of more complex computations and are therefore logically located in early educational years. However, it is notable that the document that stated a goal of developing critical thinkers wishes to accomplish its task by teaching skills.

Progressing through the years of curriculum one finds that descriptions for the Grade 12 Discrete Math course are similarly skills focused:

> **Geometry**
>
> **Overall Expectations**
>
> By the end of this course, students will:

- perform operations with geometric and Cartesian vectors;
- determine intersections of lines and planes in three-space.

(The Ontario Curriculum Grades 11 and 12, 2005, p. 45)

Even the Grade 12, workplace preparation course, Mathematics for Everyday Life, curriculum focuses on mathematical skill development rather than mathematical comprehension.

Statistics and Probability

Overall Expectations

By the end of this course, students will:

- construct and interpret graphs;
- formulate questions, and collect and organize data related to the questions;
- apply principles of probability to familiar situations;
- interpret statements about statistics and probability arising from familiar situations and the media.

(The Ontario Curriculum Grades 11 and 12, 2005, p. 67)

Do students who are taking math as preparation for the workforce really need to construct graphs? Would it not be a better use of time to focus on the last skill, that of learning to interpret statements that arise around you? The act of interpreting statistics and probability from familiar situations is finally a contextual experience that may assist in developing comprehension but it is still wedged in among a list of skills to be learned and demonstrated.

The hope is that students will become critical thinkers but they are asked to achieve those thinking skills independently since their classrooms have so much content to cover. The teaching emphasis ends up being on mathematical fact learning and mathematical skill building in order to achieve the course objectives. Thinking, inquiry and problem solving skills, while mentioned, do not receive enough time for proper development. In this way, the progression of curriculum has not produced marked changes.

Math Education and the Chinese Room

Although students are not locked in a room to learn mathematics isolated from external stimuli their learning process matches that of the person in the Chinese Room. With every grade there is a set of facts and skills that must be memorized, organized and repeated upon request. Students learn by reading rules and solutions or watching another person solve problems. They begin to identify the appropriate answer (output) for each question (input) and, eventually, are expected to memorize the complete set of basic math skills (the rule books).

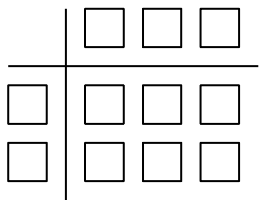
If Searle's thought experiment is accurate then students are engaged in a process of learning the formal symbol manipulation of mathematics. While they may understand the language through which they are being taught math, their understanding of mathematics remains nonexistent. They learn to perform step C, after step B, after step A, but can remain disconnected from the meaning of their actions. The introductory notes to the curriculum documents agree with Searle in their suggestions that context is necessary for learning. If the computer that looks up the answers in its earlier programming does not know what it is doing then students who look up the answers with a calculator, computer program, or memorized internal databank also do not know what they are doing. If traditional teaching strategies, focused on rule learning, persist cultural mathematical illiteracy will continue.

Teachers frequently try to get around this problem by requiring that students show their work. The provincial testing from the Education Quality and Accountability Office makes liberal use of the phrase, “explain your thinking”. These requests attempt to engage students in connecting with the process they have followed to achieve an answer to the problem. However, if they simply memorize the facts, memorize the skills and memorize an order to their steps, then, what they write down to explain their thinking is simply a transcription of the rule book lodged in their heads. Students can write out a full solution to a complex problem without any understanding of what they are writing.

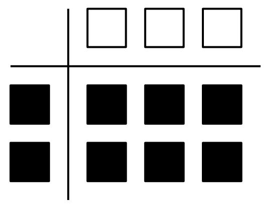
Math Education without the Chinese Room

Recent attempts to introduce mathematics through use in context have also faltered since students tend to arrive without automated retrieval skills. Our current, fast-paced society has little patience for repetitive tasks. As a result, students do not practice skills once they have accomplished them and fail to develop internal rule books. When students are given opportunities to learn multiplication through the use of algebra tiles (Figures 1 & 2) they are more likely to understand the meaning of multiplication and the use of variables within multiplication.

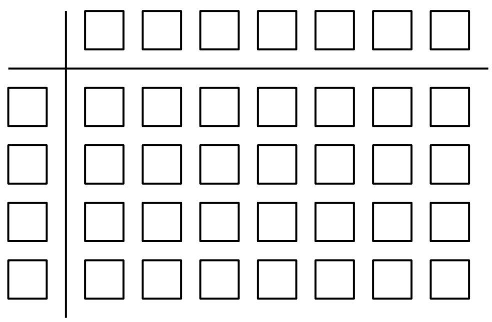
Figure 1. Algebra Tiles for Multiplication



1a.



1b.



1c.

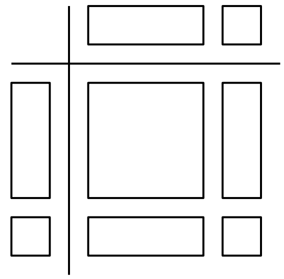
The conceptual understandings from *1a* and *1b* can be easily extended to calculate an answer for *1c*. In *1a* a rectangle with side lengths of 2 units and 3 units has an area of 6 square units. In *1b*, *1a* is extended to illustrate the flipping process used by algebra tiles to represent negative areas which is hopefully extended to more complex problems without a need for separate diagrams. 1c illustrates the process used to extend comprehension of the concept of multiplication to a larger problem. However, the process of drawing 39 small squares is time consuming and limits the time available to extend learning. Students need to memorize the common rules as well as to understand why they work.

When students learn the calculus concept of slope by walking in front of a calculator based ranger (Figure 3), they are more likely to later profess an understanding of the relationship between slope and speed.

Figure 2. Algebra Tiles as a Comprehension Aid

$$\cancel{(x+1)^2 = \xi^2 + 1}$$

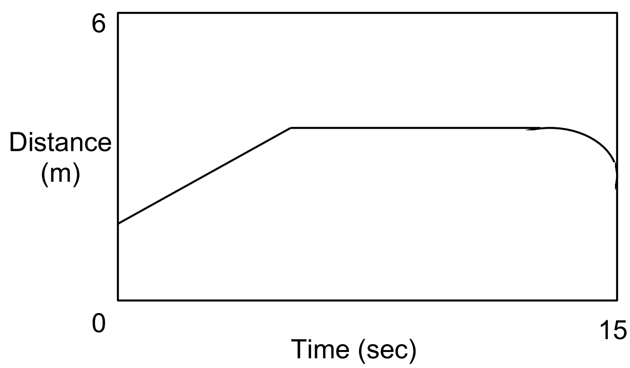
$$(x+1)^2 = \xi^2 + 2\xi + 1$$



2a. Why is this wrong? *2b*. Why is this correct?

2a illustrates a common error. *2b* illustrates the correct answer but without meaning. The algebra tile diagram illustrates how the multiplication of variables actually occurs.

Figure 3. Calculator Based Ranger



Students learn to create the following graph by starting 1.5 m from the CBR, walking at a steady pace away from the CBR for 5 seconds, standing still 3.5 m away from the CBR for 8 seconds, and then, for the final 2 seconds, moving towards the CBR at an accelerating pace.

However, if, due to time constraints, they consequently fail to spend enough time working with the rules they have learned, they will not memorize the rules and will then be unable to perform their calculations quickly enough to move on to more advanced calculations. In contrast to the person in the Chinese Room, who has memorized the rules but does not understand them, many students today understand the basic concepts but are unable to apply them to solving problems because they lack memory recall.

The person in the Chinese Room memorizes and can retrieve the rules on command. In order to apply mathematical techniques in contextual situations, students need the retrieval mastery achieved by memorizing the rule book in the Chinese Room. The current Ontario curriculum discusses teaching approaches, indicating that a variety of techniques will be needed in order to reach students with diverse learning styles and suggests that learning works best when presented in context. Public school students are not isolated in individual rooms. However, they do learn in settings isolated from context for the problems they are being asked to approach. Most students encounter at least one teacher who designs creative introductions and applications to allow for mathematical learning that is embedded in an appropriate context. Yet, in order to function in these more realistic settings, they need to already have automated retrieval and good conceptual comprehension of earlier skills. Due to time constraints, and the challenges of teaching such a diverse student body, students no longer participate in regular repetitive practice of mathematical skills and therefore do not develop these necessary retrieval skills. Thus, although their conceptual understanding may be better than that of their counterparts locked in the Chinese Room, students who have only encountered mathematics in contextual settings may be unable to solve new problems. They may have difficulties recalling an appropriate approach, or, may be incapable of accurately calculating and evaluating numerical results, or, may simply get caught in the struggle with the fact that every problem they see is a brand new problem without precedent experiences.

Success in Spite of the Chinese Room

Despite all of the challenges facing the math student we also live in a society full of sky-scrapers, channel spanning bridges, electricity and fiber optic communication. These, and many other, engineering marvels were designed and built by recipients of a Chinese Room styled mathematical education. In some cases, the working engineer or construction worker has merely become an expert at following the rule books and continues to remain in the dark about why the building really stays standing without being sheared apart by wind stresses. However, in many cases, the design engineers, electricians and construction foremen have developed internal understandings that allow them to feel their way through a plan. In these cases, they have successfully integrated their learning of background math skills from within the Chinese Room and their contextual design experiences.

During a conversation with a friend who is an artist and professed to hate all math and avoid it at all times I provided a mathematical analysis of the artistic process and an artistic analysis of a mathematical problem. A few days later, she told me that she had started seeing math everywhere and that I had messed with her view of the world. The idea that mathematics could be useful was a completely new idea for her. By drawing the connections for her, between her daily experiences and the math she had memorized, I had opened up a new understanding of the presence and power of mathematics. Until our conversation, she had conceived of math as something that she could have learned in the Chinese Room, merely a set of skills to be used in response to stimuli and used to produce appropriate output. However, with a little assistance, she was still able to comprehend math despite the constraints in her prior experience.

Some people will learn in any setting and others can learn in any setting with only a little assistance. Thus, regardless of their exposure experiences, to the Chinese Room, or to contextualized math without fact recall, they will develop both abilities and can be said to have learned to understand mathematics. The next section of this paper will examine the learning process that occurs inside the Chinese Room.

Learning in the Chinese Room

Human Brains in the Chinese Room

Despite the constraints of the Chinese Room and the isolation that inhibits learning, the thought experiment is contingent upon there being a human being within the room. Human brains are much more complex than Searle credits and some of them will make unexpected leaps that create comprehension.

In the earlier VCR example, you were left to find your own path to success by following detailed rules precisely. However, some people found this task easy to perform and could pick up any remote control, facing any VCR and successfully program it to record as desired. It is true that there is some later feedback from the system in terms of whether or not the program you wanted was recorded. However, some people managed to understand the systems even before the feedback was received. Antonio Battro has referred to people who learn in these situations as possessing digital intelligence (Gardner, 2003).

Some people learn languages by reading books or listening to music. They manage the task of assigning meaning to symbols and sounds without feedback on their understanding or progress and without contextual use of the language they are attempting to learn. Another subset of people can learn languages through reading when given the appropriate rule books (i.e. a dictionary and a grammar book). Both of these groups of human beings would be likely to learn Chinese while working inside the isolated Chinese Room. It might not be an ideal learning environment for them, but they would still learn.

Similarly, many people possess innate mathematical thinking. These people develop a feel for all things numerical or abstractly mathematical. Despite learning math within a Chinese Room context they will automatically make connections between seemingly isolated skills and between the skills and their environment. We often refer to these people as geniuses and rely on them to design new building techniques, new ideas for communication and to support our societal growth. If the person in the Chinese Room possessed one of these brains, then they would learn Chinese despite the challenges of the situation.

Perhaps the Computer Can Learn to Think

If human brains can learn despite exposure to learning experiences that consist of reading and memorizing rules. Then, perhaps the computer can learn as well. It may be that the current programming (i.e. rule book) is insufficient but that changes will enable greater cognitive comprehension. Or, it may be that the computer learns and comprehends in a manner similar to only a few human brains. Or, perhaps Searle is correct and the computer understands nothing. However, in this case, I believe that the Chinese Room only provides part of the argument.

Conclusion

The standard television example of complex mathematics involves two trains on the same track headed towards each other. This problem is presented as complicated and mind-boggling. However, it can be solved with the application of simple math facts and math skills. The reason it appears challenging is that it applies a context to the use of those skills. Yet, the context generally remains remote and is rarely demonstrated with an actual train on an actual track. For students who have learned in traditional mathematics classrooms the context is unexpected. If provided with the rules associated with trains on a track they will follow them to an answer but do not understand the connection between their answer and the moving trains. This group of students supports the claim that learning within the Chinese Room does not lead to understanding. Students who have learned with contextualized situations but without memorizing math facts are likely to understand the problem but struggle to get exact numerical answers. A few students who have memorized their math facts from rule book learning will make internal comprehension leaps extending their facts to the appropriate application and will see their way to an easy solution. This last group of students refutes the claim that the Chinese Room argues against artificial intelligence.

Searle's Chinese Room thought experiment provides powerful insight into human cognition but its application to computer intelligence remains uncertain. Most human beings require both the rule book memory work of the Chinese Room and contextual applications in order to learn and comprehend. In the case of mathematics education, the focus on skills has fostered a fear of mathematical thinking and supported the idea that truly understanding math is rarely possible. Isolation from purpose affects learning of mathematics in much the same way that isolation from interaction affects learning of Chinese by the person in the room. However, some people develop intense, creative understandings of mathematics despite being taught to simply follow the rules. Their ability to learn within a system that teaches math in isolation implies that artificial intelligence may also be able to resolve search and retrieval programming into understanding.

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