Games and Puzzles in Mathematics

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Abstract

Games are a widely used tool in Canadian and Chinese classrooms to enhance students' mathematical learning. Math games are most commonly found in the lower grades (grades one to three), with more than half of these games focusing on number skills. Calculation games are the most prevalent, while games related to other math concepts, such as geometry, algebra, and statistics, are less common. While many of these games incorporate hands-on materials, engaging contexts, and elements of student autonomy to foster an understanding of mathematical concepts, most remain at a basic level of mathematics. These games often rely on question-and-answer formats to practice fundamental math concepts and skills and lack connections to big mathematical ideas. Furthermore, they do not offer opportunities for students to share their thinking strategies and original products. To address these limitations, integrating new technologies, such as coding, could provide a solution. In our work in grades 3-8 classrooms, we note that coding has the potential to create more intellectually stimulating math engagement that not only makes learning easier but also encourages deeper thinking and understanding, by providing a lower floor for younger students to participate while offering a higher ceiling that challenges them to think hard.

Keywords: *Math games, puzzles, coding, Canada, China.*

1. Introduction

Math games are widely used in teaching and learning ([1]) and are integrated into the curricula of both China and Canada. The recently updated math curriculum standards in Ontario, Canada, and China emphasize the role of math games, which are frequently featured in textbooks and academic journal articles in both countries. With the widespread adoption of electronic devices, digital math games are also being developed and integrated into educational settings. Given this, a closer examination of the current design and use of math games in teaching resources is warranted. Such an examination could help identify potential limitations in their design and application, as well as explore ways to enhance the quality of math games.

Oldfield defined a math game as an activity involving a challenge against a task or opponent, governed by a set of rules, with a defined endpoint, and aimed at achieving specific mathematical cognitive objectives ([2]). They are believed to influence students' knowledge acquisition, skills development, and attitude formation. Research has shown that math games can promote students' mastery of fractions ([3], [4], [5], [6], [7]), and strengthen students' number sense, including skills such as counting, comparing, composing or decomposing, and calculating ([8]). They also help to foster students' understanding of symbolic algebra ([9]) and improve students' spatial sense and perception ([10]).

In terms of skill development, math games can enhance students' problem-solving abilities ([11], [12], [13]) and mathematical reasoning ([14]), as students are required to respond to the various demands of the games. They are considered effective for promoting creative thinking skills ([15]), since they present unfamiliar contexts and ever-changing responses from others, encouraging children to break from conventional thinking and generate new, simple ideas ([16]). Additionally, math games are believed to help improve students' critical thinking skills ([17]) by engaging students in active learning processes and requiring them to apply their knowledge to solve non-routine problems and build new understanding ([18]). Furthermore, they are consistently used to enhance communication and collaboration skills, bridging the gap between classroom learning and real-world practice ([19]).

Regarding students' dispositions, math games are thought to reduce math anxiety ([20], [21]) and foster positive attitudes toward math ([22], [23]).

However, despite their many advantages, some scholars argue that math games do not always have a positive impact and may even have negative effects on certain students' learning since many math games are designed and used in a superficial or shallow way ([24]), leading to off-task behavior,

unhealthy competition, and dependency ([25]). Additionally, they can contribute to anxiety or jealousy among students ([24]).
Therefore, this research aims to explore the design and use of math games in Grades 1–6 in China and Canada, with the goal of identifying effective strategies for developing high-quality math games. Additionally, it highlights the use of coding puzzles in Canadian classrooms from Grades 3–8, offering a potential pathway to enhance students' mathematics learning. The following research questions will be answered:

1) How are math games designed and used in China and Canada in grades 1-6?
2) What are the key features of an effective math game?
3) How are coding puzzles integrated into Grades 3–8 Canadian classrooms?
4) Why can coding activities enhance students' mathematical learning?

2. Methodology

This research is theoretically grounded in constructivism and social constructivism. From a constructivist perspective, learning is not a passive process of receiving information; rather, it is a constructive process where learners actively build an internal representation of knowledge and develop a personal interpretation of their experiences ([26]). In the social constructivist view, meaning is constructed through interactions with others and the surrounding environment ([26]). Constructivism and social constructivism emphasize the following themes, which are relevant to this study. First, students' agency and engagement are crucial for learning. Second, learning is a process in which knowledge should be actively constructed by students, by using previous experience, hands-on materials, and interacting with others and surroundings.
In this research, the first part examines the design and use of math games found in textbooks, journal articles, and online resources in Grades 1–6 in China and Canada. These games are categorized and analyzed based on three dimensions: general characteristics, mathematical focus, and game level. The general features include the number of games and their distribution across different grade levels. Other dimensions considered are the number of participants, the use of hands-on materials, whether the games are competitive or collaborative, the context involved, students' roles, and whether the games are directly played or skill-driven. The mathematical focus includes the specific math concepts addressed, and the level of the games is based on Bloom's Taxonomy (remembering, understanding, applying, analyzing, evaluating, and creating).
In the second part, some coding puzzles' utilization from grades 3-8 in Canadian classrooms is demonstrated and analyzed.

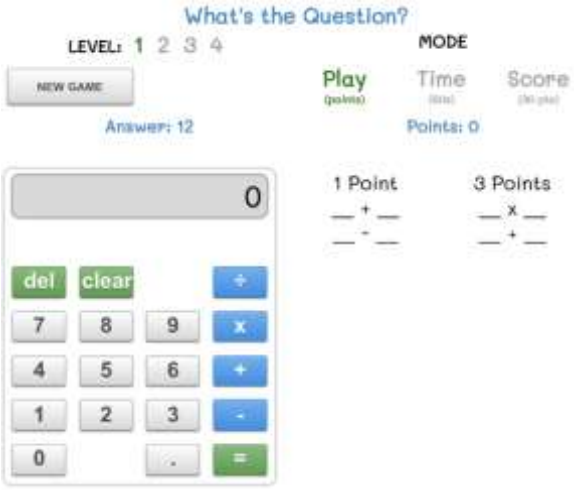
3. Math Games' Design and Use in China and Canada in Grades 1-6

The research shows that the general features of math games in China and Canada for Grades 1–6 are quite similar, whether found in textbooks, academic journals, or online resources. First, there is a greater number of math games in the lower grades (Grades 1–3) compared to the upper grades.
Second, most games are multiplayer and frequently involve the use of tools. A significant proportion is non-competitive, with the majority rooted in mathematical contexts and only a few connected to real-life scenarios.
Additionally, students are, to some extent, encouraged to take an active role in controlling and engaging directly with the games, rather than acting as passive participants or simply treating the games as math exercises or background content. Most games are skill-based, with only a small number incorporating elements of chance.
In terms of mathematical focus, Canada covers a wider range of math concepts. However, in both countries, over half of the games focus on numbers, particularly number recognition and calculation. Specifically, counting, comparing, place value, number representation, and integer operations are the most common topics. Fewer games address geometry, statistics, and probability.
Regarding games' levels, about 70% of math games in both countries fall within the first three levels of Bloom's Taxonomy: remembering, understanding, and applying. Among these, most of the games in both countries are at the "understanding" level, using a question-and-answer format to practice basic math concepts and skills. In other words, the majority of the games are concentrated at lower cognitive levels, with fewer math games involving analyzing, evaluating, or creating.

4. Games with Deeper Mathematics

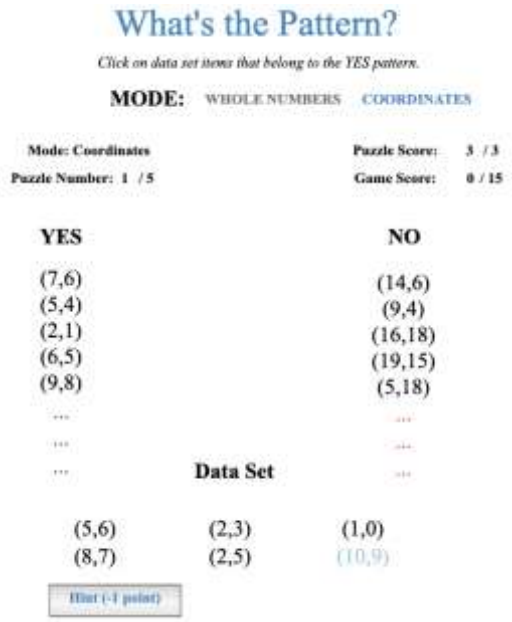
In this section, we consider 2 math games designed by our research group that allow students to engage with a greater range of mathematics.

4.1 What is the Question?



The game "What is the question?" (available at https://imaginethis.ca/apps/number/question) provides an answer (like 12) and asks students to create questions that have that answer. Addition and subtraction questions are awarded 1 point, and multiplication and division questions are awarded 3 points. Students use the calculator interface to create the questions. Some sample questions are listed below:
5+7 = 12, 20-8 = 12, 3x4 = 12, 36/3 =12
The game may be played at 4 different levels, with larger answers used for higher levels.
The game may also be played in 3 different modes. I Play mode, players may spend as much time as they want on each answer. In Time mode, students have 30 seconds to get as many points as possible. In Score mode, a target score is given, and students try to reach the score in the shortest time possible. Students may play the Time and Score modes in pairs, competing to get the highest score or the shortest time, respectively.
This game is different from most number games in the above research, as students need to think creatively to find as many questions as possible that match a given answer.

4.2 What's the Pattern?



The game "What's the pattern?" (available at https://imaginethis.ca/apps/number/pattern) has 2 Modes, Numbers and Coordinates. For each mode, there is a Yes column and a No column. The Yes column has a pattern in it, which students try to determine. They click on the data in the Data Set that they think, or guess, belongs in the Yes column, to collect more information to solve the puzzle. Each correct guess gives them a point.
Such puzzles are conceptually focused and build on Jerome Bruner's work on work on *Concept Formation* (understanding that different concepts have different attributes) and Concept Attainment (understanding how the attributes determine what belongs and what does not).

5. Conclusion

This research reveals that although math games are widely used in Chinese and Canadian teaching resources from Grades 1 to 6, a critical issue remains: these games often lack both depth and breadth from a mathematical perspective. On the one hand, the mathematical content is largely limited to number-related concepts; on the other hand, the activities often fall short of promoting true active learning. Most games focus primarily on reinforcing math facts and basic skills, rather than encouraging exploration of mathematical structures and relationships. As a result, the learning they support tends to be superficial.
Therefore, beyond the basic features—such as being appropriately challenging (aligned with students' competencies), incorporating elements of fantasy (narrative, imagination, and sensory engagement), fostering curiosity (through novel experiences), and offering freedom (such as student control and opportunities to try again)—a well-designed math game should also promote the active construction of mathematical knowledge and support a deep understanding of mathematical concepts. The 2

examples we shared in Section 4 point to some potential directions for designing games that engage students with core conceptual mathematics.

REFERENCES

[1] Iljazi, T, "Teaching and Learning Mathematics Supported by Games," *Journal of Educational Research - EDUCATION*, vol. 6, no.11-12, pp. 93-100, 2024. https://doi.org/10.62792/ut.education.v6.i11-12.p2642

[2] Oldfield, B. J, "Games in the Learning of Mathematics: 1: A Classification," *Mathematics in School*, vol. 20, no.1, pp.41–43,1991. http://www.jstor.org/stable/30214754.

[3] Lim, T., Lee, S., & Ke, F, "Integrating Music into Math in a Virtual Reality Game: Learning Fractions," *International Journal of Game-Based Learning*, vol.7, no.1, pp. 57-73, 2017. https://doi.org/10.4018/IJGBL.2017010104

[4] Masek, M., Boston, J., Lam, C. P., & Corcoran, S, "Improving mastery of fractions by blending video games into the Math classroom," *Journal of Computer Assisted Learning*, vol. 33, no. 5, pp. 486–499, 2017. https://doi.org/10.1111/jcal.12194

[5] McKevett, N. M., Kromminga, K. R., Ruedy, A., Roesslein, R., Running, K., & Codding, R. S, "The Effects of Motion Math: Bounce on Students' Fraction Knowledge, *"Learning Disabilities Research & Practice*, vol. 35, no. 1, pp. 25–35, 2020. https://doi.org/10.1111/ldrp.12211

[6] Riconscente, M. M.," Results from a Controlled Study of the iPad Fractions Game Motion Math." *Games and Culture*, vol. 8, no. 4, pp. 186-214, 2013. https://doi.org/10.1177/1555412013496894

[7] Zhang, L., Shang, J., Pelton, T., & Pelton, L. F," Supporting primary students' learning of fraction conceptual knowledge through digital games," *Journal of Computer Assisted Learning*, vol. 36, no. 4, pp. 540-548, 2020. https://doi.org/10.1111/jcal.12422

[8] Lathifah, N. N., & Maryanti, R.," Basic Arithmetic Learning through Math Online Games for Elementary School Students during the Pandemic, *"Indonesian Journal of Multidisciplinary Research*, vol. 1, no. 2, pp. 379–384, 2021. https://doi.org/10.17509/ijomr.v1i2.38546

[9] McCaffrey, T., & Matthews, P. G., "An Emoji Is Worth a Thousand Variables," *The Mathematics Teacher*, vol. 111, no. 2, pp. 96-102, 2017. https://doi.org/10.5951/mathteacher.111.2.0096

[10] Zeng, J., Hu, R., & Shang, J.," Design and Development of an Educational Game for Facilitating Spatial Ability and Mathematics Learning," *2021 International Symposium on Educational Technology (ISET)*, pp. 275–280, 2021. https://doi.org/10.1109/ISET52350.2021.00065

[11] Demirel, T., & Karakus Yilmaz, T.," The effects of mind games in math and grammar courses on the achievements and perceived problem-solving skills of secondary school students, *"British Journal of Educational Technology*, vol. 50, no. 3, pp. 1482-1494, 2019. https://doi.org/10.1111/bjet.12624

[12] Ke, F.," Mathematical problem solving and learning in an architecture-themed epistemic game," *Educational Technology Research and Development*, vol. 67, no. 5, pp. 1085–1104, 2019. https://doi.org/10.1007/s11423-018-09643-2

[13] Ke, F., & M. Clark, K.," Game-Based Multimodal Representations and Mathematical Problem Solving," *International Journal of Science and Mathematics Education*, vol. 18, no. 1, pp. 103-122, 2020. https://doi.org/10.1007/s10763-018-9938-3

[14] Buchheister, K., Jackson, C., & Taylor, C. E.," Maths games: A universal design approach to mathematical reasoning," *Australian Primary Mathematics Classroom*, vol. 22, no. 4, pp. 7-12, 2017.

[15] Kartika, Y., Wahyuni, R., Sinaga, B., & Rajagukguk, J.," Improving Math Creative Thinking Ability by using Math Adventure Educational Game as an Interactive Media, *"Journal of Physics: Conference Series*, vol. 1179, no. 1, p.12078, 2019. https://doi.org/10.1088/1742-6596/1179/1/012078

[16] Bertoni, A., & Maffia, A.," Promoting creative insubordination using Escape Games in mathematics," *International Journal of Mathematical Education in Science and Technology*, vol. 55, no. 4, pp. 1054–1064, 2024. https://doi.org/10.1080/0020739X.2022.2113468

[17] Widiyatmoko, A., Utaminingsih, S., & Santoso," Android-based math learning to improve critical thinking," *Journal of Physics: Conference Series*, vol. 1823, no. 1, p.12091, 2021. https://doi.org/10.1088/1742-6596/1823/1/012091

[18] Nurjanah, R.," Development of Math Set Game to Improve Critical Thinking Skills Student of Class VII Material Set," *AlphaMath: Journal of Mathematics Education*, vol. 8, no. 1, p. 29, 2022.

https://doi.org/10.30595/alphamath.v8i1.13042
[19] Lucas, C., Schindel, T. J., Saini, B., & Paslawski, T.," Game changer: Pharmacy students' perceptions of an educational "Party Hat" game to enhance communication and collaboration skills", *Currents in Pharmacy Teaching and Learning*, vol. 12, no. 4, pp. 442-449, 2020. https://doi.org/10.1016/j.cptl.2019.12.033
[20] Isbister, K., Karlesky, M., Frye, J., & Rao, R.," Scoop! A movement-based math game designed to reduce math anxiety," *CHI '12 Extended Abstracts on Human Factors in Computing Systems*, pp. 1075–1078, 2012. https://doi.org/10.1145/2212776.2212389
[21] Reyes, J. D. C.," Increasing Self-efficacy and Alleviating Anxiety using Touch Math and Instructional Games: An Intervention for Low Performing Seventh Graders," *Journal of Humanities and Education Development*, vol. 1, no. 2, pp. 59-74, 2019. https://doi.org/10.22161/jhed.1.2.2
[22] Mavridis, A., Katmada, A., & Tsiatsos, T.," Impact of online flexible games on students' attitude towards mathematics," *Educational Technology Research and Development*, vol. 65, no. 6, pp. 1451–1470, 2017. https://doi.org/10.1007/s11423-017-9522-5
[23] White, K., & McCoy, L. P.," Effects of Game-Based Learning on Attitude and Achievement in Elementary Mathematics," *Networks: An Online Journal for Teacher Research*, vol. 21, no. 1, pp. 1-17, 2019. https://doi.org/10.4148/2470-6353.1259
[24] Bai, S., Hew, K. F., & Huang, B.," Does gamification improve student learning outcomes? Evidence from a meta-analysis and synthesis of qualitative data in educational contexts," *Educational Research Review*, vol. 30, p.100322, 2020. https://doi.org/10.1016/j.edurev.2020.100322
[25] Andrade, F. R. H., Mizoguchi, R., & Isotani, S.," The Bright and Dark Sides of Gamification," *Intelligent Tutoring Systems*, vol. 9684, pp. 176–186, 2016. https://doi.org/10.1007/978-3-319-39583-8_17
[26] Amineh, R. J., & Asl, H. D.," Review of Constructivism and Social Constructivism," Journal of Social Sciences, Literature, and Languages, vol.1, no.1, pp.9-16, 2015.