"I Just Won Against Myself!": Fostering Early Numeracy Through Board Game Play and Redesign

Shayla Jaques, Beaumie Kim, Anna Shyleyko-Kostas and Miwa A Takeuchi

Shayla Jaques is the math learning leader at an inner-city elementary school in the Calgary Board of Education, in Calgary, Alberta. She teaches STEM (science, technology, engineering and math) to students in Grades 1–6. She is passionate about not only exploring new learning approaches for young learners but also playing and designing board games.

Beaumie Kim is an associate professor of learning sciences at the Werklund School of Education, University of Calgary. Her work focuses on empowering learners to design learning resources and tools using games. She carries out her work in collaboration with teachers and students as design partners and by observing their interactions, discourse and artifacts.

Anna Shyleyko-Kostas is a kindergarten teacher at an inner-city elementary school in the Calgary Board of Education. She is passionate about hands-on, play-based learning in the early years and believes in providing authentic experiences for her young students. She also enjoys playing games and spending time outside with her family.

Miwa A Takeuchi is an associate professor of learning sciences at the Werklund School of Education, University of Calgary. Her expertise and research interests include equity and diversity in early mathematics/STEM education and the co-design of robust learning environments with learners, teachers and parents.

Abstract

Children can develop a variety of mathematical concepts, as well as a positive relationship with mathematics, through playing and redesigning board games. In this article, the authors introduce the process of integrating board game play and redesign into the early mathematics classroom. Presenting cases from a diverse school, they highlight learning opportunities that fostered early numeracy. They discuss how children demonstrated their understanding of integrated numeracy (including subitizing, ordinality and cardinality of number, the area model of multiplication, spatial reasoning, and problem posing and solving). The project not only fostered children's early numeracy but also helped them to develop a positive relationship with mathematics and social rules and to see themselves as designers, problem solvers and creative people.

During the early years, children can develop a wide variety of concepts through everyday practices. Play is a meaningful context in which children can develop mathematical concepts, symbolization and representation (Charlesworth and Leali 2012; van Oers 2010). Through play, children develop key concepts such as arithmetic and counting, one-to-one correspondence, estimating, spatial reasoning, measuring, understanding shapes, logical classification, comparing, ordering, and understanding parts and wholes (Charlesworth and Leali 2012; Clements and Sarama 2014; Ginsburg, Inoue and Seo 1999; Ginsburg, Lee and Boyd 2008).

In the context of game play, McFeetors and Palfy (2018) focused on the development of strategy and mathematical reasoning in students when they played games such as Gobblet Gobblers, Othello, Tic Stac Toe and Go. Centralizing playfulness in early numeracy can also foster a positive relationship with mathematics (Takeuchi, Towers and Plosz 2016). Alberta Education defines *numeracy* broadly as "the *ability*, *confidence* and *willingness* to engage with quantitative or spatial

information to make informed decisions in all aspects of daily living."[1]

In this article, we present a particular context of early numeracy development—playing and redesigning board games. Creating artifacts has a special place in the mathematics classroom. Children understand new ideas and form their identities through creating and inventing symbols and artifacts (Kim, Tan and Bielaczyc 2015). In their play, they invent rules while developing key concepts. Game design encompasses both the creation of artifacts and the invention of rules. In designing board games, learners use their bodies by creating game pieces and create a coherent system in which their invented rules govern the play (Kim and Bastani 2017), and they also invent alternative ways to do mathematics (Barta and Schaelling 1998). Learners model, play and revise the invented system, in which players engage in movements and actions and make more sense of it through play (Salen and Zimmerman 2006).

Few studies exist that focus on early learners' design of games for their mathematics learning. A rare example of engaging children in mathematical game play and design in the early years is Barta and Schaelling's (1998) work on Grades 1 and 2 students' construction of a Native American counting game. The children created the counting game using sticks, played the game and then generated new rules, becoming vehicles of their own learning.

Through modelling, learners quantify, categorize and systematize relevant objects, relationships and actions (Lesh and Doerr 2003). In this article, we highlight the experience of redesigning an existing board game and discuss how children's early numeracy was fostered, along with their positive relationship with mathematics.

Project Context: Board Game Play and Redesign for Mathematics Teaching and Learning

This article is based on a research–practice partnership in an inner-city school in Alberta. The school had a diverse population of students, 90 per cent of whom were English-language learners (ELLs). The school development plan centred on teaching ELLs complex concepts through rich tasks, expanding their understanding regardless of language.

The school took on the project of playing a variety of board games in every classroom and exploring the possibility of redesigning those games or changing some rules. Through the partnership, we held co-design workshops with teachers, researchers, and a professional board game designer and mathematician (Gord Hamilton).[2] We played and then redesigned a variety of games (Hex, Codenames, Aggression, Qwirkle); built our understanding of game play and idea iteration; and came up with ideas for facilitating a similar experience for students in the classroom. Giving the teachers time together to work through the first steps of the game redesign process helped them visualize its place in their own classrooms.

In this article, two teachers recount how board game play and redesign lived in their classrooms (Grades 3/4 and kindergarten) in the first year of the research partnership. In both classes, students' activities in terms of progressing their game redesigns took varying forms, including the following:

1. Playing games and noticing patterns of winning or losing
2. Brainstorming new rules
3. Redesigning the game and playtesting
4. Creating rule books
5. Making good copies of the game
6. Inviting others to play (final showcasing)

Starting with playing the games (before thoroughly reading the official rules) was important as it demonstrated the need to understand the rules in order to participate fully in the game. Some of these activities were planned, but others emerged as we worked with the students.

Redesigning Inversé in Grades 3/4 (Teacher-Author 1)

In my Grades 3/4 classroom, I chose many games to play. The class's mathematics learning at this point focused on arrays and basic multiplication. My students immediately noticed that many board games have arrays and grids built into them.

Playing and Noticing

We began playing board games in October, when I brought in my games (such as Tsuro, Connect 4 and Codenames). We also borrowed some popular games from the school library (Qwirkle, Triominos, Guess Who? and Jenga).

The biggest challenge at this stage was ensuring that the students understood the official rules of the games. Many groups played with their own house rules or did not play competitively (for example,

placing pieces without keeping score, or working together to create patterns with the pieces). To tackle this challenge, we played several games as a whole class. I chose a small group of students to play with, and the rest watched the game play. We made an anchor chart of the most important rules of each game—rules that the students often misunderstood or overlooked when they played on their own.

As we incorporated board games into our classroom culture, students deepened their understanding of the official rules, as well as the social rules (such as turn-taking, graceful winning or losing, and basic game play strategies). They began to plan a turn or two ahead and to take on their opponents' perspectives to develop an effective defence. Playing a wide variety of games helped them build up a vernacular around gaming. In classroom discussions, we began comparing games based on the balance of luck and strategy, the number of players, the length and complexity, and even how the first player was chosen.

After the students had developed a foundational understanding of board games, I introduced the project. We were going to redesign one of our class favourites, Inversé (Figure 1). Inversé involves a 12-by-12 grid board and wooden blocks of five colours and five shapes, each with a volume of 48 cubic units. The goal is to be the last player to play a piece, placing it in such a way that your opponent cannot make a legal move.

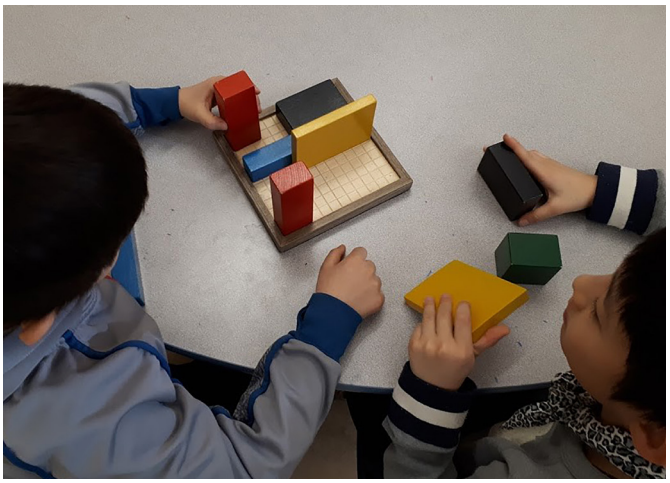


FIGURE 1. Two Grade 3 students playing Inversé.

I chose Inversé because it is short (less than two minutes per game) and simple to teach. It has only three rules: pieces of the same height can't touch, pieces of the same colour can't touch, and pieces of the same colour can't be placed in the same orientation. It also has lots of depth in terms of mathematical thinking (spatial awareness, estimating area and height, and comparing the size and shape of rectangles).

We spent a couple math classes honing our Inversé skills, playing tournaments and keeping track of the success of various strategies. We documented how many times the first player was the winner, and how many times the person who played the yellow piece first was the winner. This deeper understanding of the system of Inversé was combined with continuous but more-focused playing and noticing.

Brainstorming New Rules

I challenged my students to find a way to make Inversé a two-dimensional game, and I asked them what rules would have to change and what rules they could potentially keep. For example, we had learned that the Inversé pieces do not all fit on the board at once, and the students realized that they would have to consider the relationship between the board size and the number of pieces. As a whole class, we brainstormed possible variations, such as using a shape other than rectangles, adding a third player or changing the rules about which tiles could touch. I recorded the students' ideas during this brainstorming session (Figure 2).

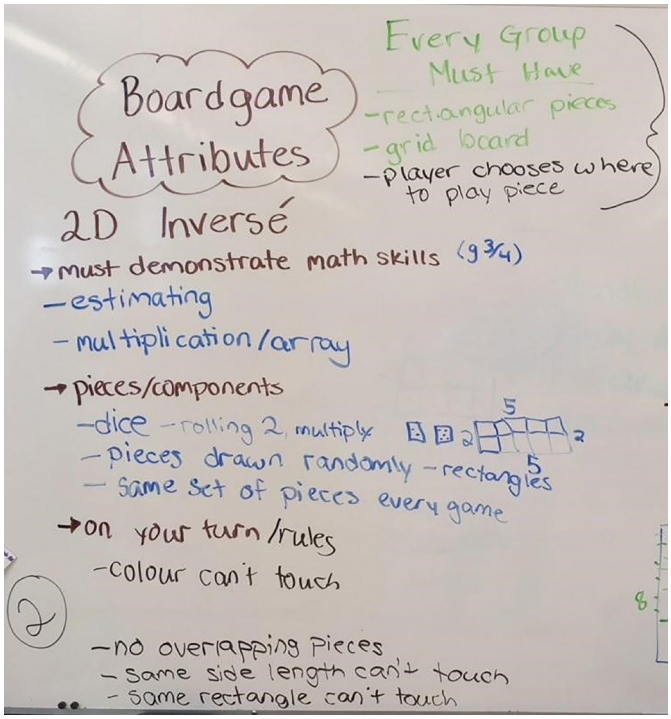


FIGURE 2. Recording student-generated ideas during the brainstorming phase.

We also spent time brainstorming the mathematics we saw in Inversé and which of those skills might transfer to the students' redesigns. We

explored questions such as, "Which piece is the biggest?" Students learned about measurement and estimation, and they were able to verbalize their estimates of arrays and areas. (For example, one student said, "I don't think my piece will fit there. That spot is too skinny.") Students then practised mathematical vocabulary, such as *longest*, *widest* and *tallest*. They measured the area, the length and even the volume of the pieces by rebuilding them with unit cubes. Inversé also allowed them to practise their spatial reasoning as they oriented the pieces in different ways and visualized how pieces of different sizes might fit together.

After our initial class discussion about redesigning the game, I gave the students time to individually brainstorm new rules and components. Then I placed them in groups of two or three, based on their initial ideas.

Redesigning and Playtesting

We spent several classes redesigning Inversé by refining the students' initial ideas; creating rough copies out of construction paper; and playtesting and adjusting the rules, pieces and boards (Figure 3).

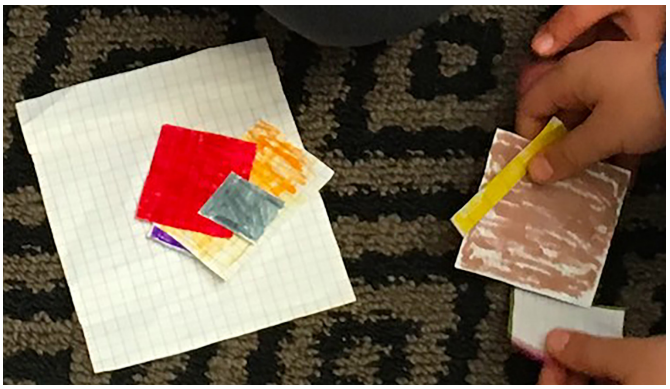


FIGURE 3. One group's paper rough copy of their Inversé redesign.

The redesign process is complicated, even more so when children are in heterogeneous groups, with a range of language, math and social skills. This project allowed for scaffolding, as students had agency over the complexity of their designs and could lean on their group members when they felt challenged by particular aspects of the project.

The biggest challenge as a teacher was keeping the groups on track to finish their games on time; some groups spent multiple class periods debating a single rule, whereas others were finished and ready to create a good copy of their game after just a few days. The strategy I used to help the students move forward and make progress every day was to provide checkpoints and deadlines, without taking away their agency and choice. For example, after the first week I said, "By the end of today your group should have decided on whether you are creating pieces to be placed or using a blank board that the players can draw on." This gave them a few options and left the project open-ended enough for customization, while also narrowing their focus so that they could make a choice and move on to the next step. This process was organic and responsive rather than premeditated; when I felt that most groups were ready to move on, I presented the deadline and the choices to the remaining groups.

When many of the groups were struggling to make a decision about the same component of the game, we talked as a class and wrote down all their ideas. This gave them a jumping-off point, and each group could then zero in on the idea that would work best for their game.

It was essential for the students to playtest their games as often as possible so that they could adjust the games when they were too easy or too difficult, or if they found that the first player always won.

Creating Rule Books

Once all the groups were happy with their new game designs, we moved on to creating rule books.

The students learned how to articulate the mechanics of their game, the procedures of a player's turn and the special placement rules they had chosen. As they playtested their games over and over, they constantly revised their rule books, adding more details to clarify the systems of their games.

Many groups who found the complex language and layout of traditional rule books challenging chose to explain the rules of their games through photos or drawings (Figure 4). These ELL students used symbols such as a check mark and an X to clarify which moves were allowed and which were against the rules.

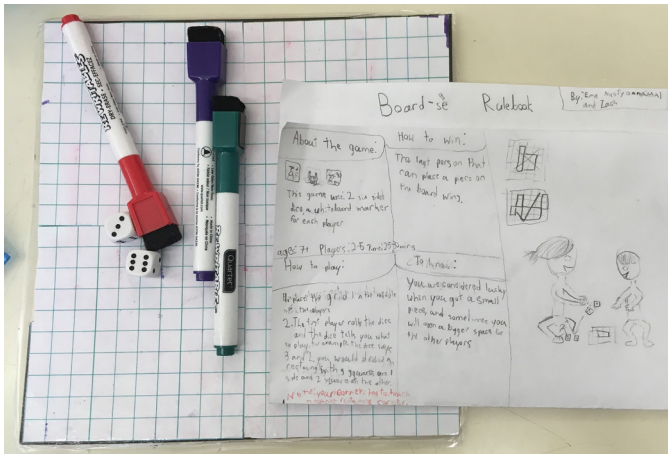
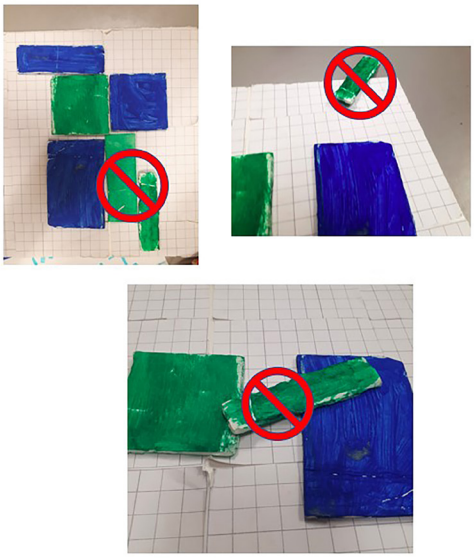


FIGURE 4. A rough copy of a rule book, with headings, pictures and symbols.

After finishing rough copies of their rule books and receiving feedback from me and from their Grade 6 buddies, my students worked with the older students to type up the rule books and print them out (Figure 5).



How to Win

You win if you are the last player to play a piece. If no one else can play a piece then you win! You are trying to strategize to block your opponent so they can't fit their pieces.

FIGURE 5. One group's rule book, using photos and symbols, created with the help of an older student.

Creating Good Copies of the Games

With their rule books complete, students moved on to creating good copies of their games out of materials that were more durable.

This proved to be challenging, as many of their rough copies had been created using tiny pieces of construction paper. They wanted to make a game that was as engaging to play as the original Inversé, which uses large, brightly coloured wooden blocks. However, the relationship between the size of the pieces and the size of the game board was vital to making their games work.

I gave the students time to struggle with this problem before introducing some tools that might help, including graph paper in various sizes, rulers and unit cubes. One group figured out how to measure the size of their pieces with the smaller-sized graph paper and then count out the same units on the larger-sized graph paper to ensure that the ratios were intact. The rest of the class gathered around to watch them use this method and then went back to their own games. Some groups borrowed this idea, and others used it as inspiration and went on to use rulers and multiplication to create larger versions of their pieces.

Showcasing Our Games

After six weeks of playing, noticing, planning, designing and creating, students finally had games they were proud to produce. We talked about how designers get their ideas and products out to the public, and many students suggested using flyers and brochures.

We created an invitation to send out to families, asking them to participate in our board game night. Many families and staff members showed up after school one afternoon, and the students were thrilled to teach them the rules of their games and see the games being played by members of the community.

Since then, these student-created board games have been added to our school library's games collection, and children can sign them out to play at home or at school.

Outcomes

This game redesign project changed how my students approached mathematical tasks, design thinking and group work. They learned that creating high-quality work takes time, and they felt a sense of satisfaction when they were able to produce and showcase that level of quality.

They also showed growth in specific mathematics skills. As a result of the nature of the design project, each group of designers produced a different type of game that targeted different mathematics skills.

For example, a group of three that included a recent Chinese immigrant student created a game combining the principles of the traditional Chinese game Go with the area-based themes of Inversé. In their game, players were to roll two dice and create a rectangle with the area shown on the dice, trying to surround their opponent's rectangles (Figure 6). These learners developed a deeper understanding of the relationship between area and side length as they worked out the best ways to orient their rectangles.

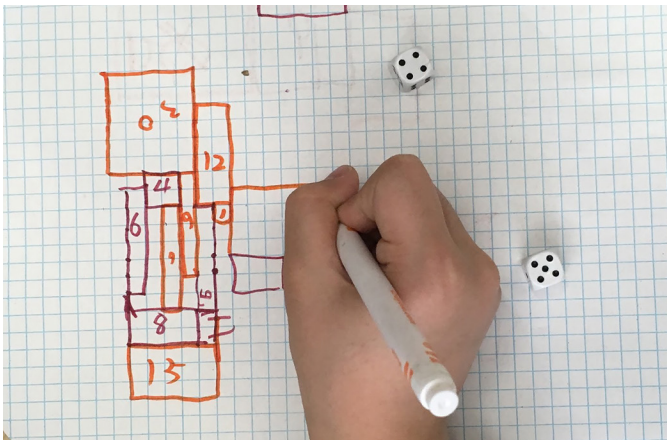


FIGURE 6. A game designed using the principles of the Chinese game Go.

Meanwhile, another group developed a three-player game in which the goal was for players to fill the space with their own pieces and not leave space for opponents (Figure 7). This group explored the concepts of shape composition, combining area and arrays.

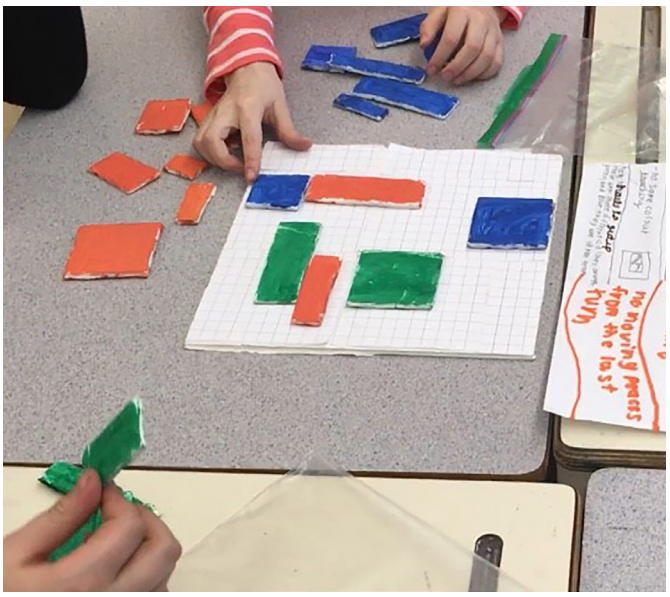


FIGURE 7. A three-player fill-the-space game.

Redesigning Connect 4 in a Kindergarten Classroom (Teacher-Author 2)

In my kindergarten classroom, I introduced the game Connect 4 to my students. Through play, we were able to use mathematics vocabulary, and the children's redesign ideas emerged from their own need to be playful.

Playing and Noticing

I had Connect 4 set up on a table when the students arrived. As they approached the table, some commented that they had the game at home. Some said, "I know this game!" Others picked up the coloured playing chips and started dropping them into the grid.

In a short time, the sense of excitement grew as the students took turns at the table, and many gathered to watch what their peers were doing. Something about Connect 4 connected with this group of children more than the other games I introduced. They would go to the Connect 4 table first (despite having other activity options), watch their peers play while waiting for their turn, and sound joyful when talking about the game.

In the beginning, I gave the students time to interact with the game and play it in their own way. Some talked about the rules with each other, stating the rules as they understood them. Others enjoyed dropping chips at random into the grid and hearing the clinking sound. Others used the chips to make patterns or stacked them to build towers.

Soon, I brought more copies of the game into the classroom to allow more students to interact with it. We had many small-group conversations about game rules (for example, how the rules one student played by could be the same as or different from the rules another student played by), as well as social rules (such as what players should do with their hands while waiting for their turn, whether it is OK for players to cover the opening of the grid with their hands and how to win gracefully). We also talked about the object of Connect 4 and what it means to win the game. This led to larger group conversations and documentation so that children had a shared understanding of all aspects of the game.

There was also mathematical vocabulary to teach, like *grid*, *line*, *vertical*, *horizontal* and *diagonal* (Figure 8). The students' interactions with each other and with the game guided the conversations and learning intentions in our work.

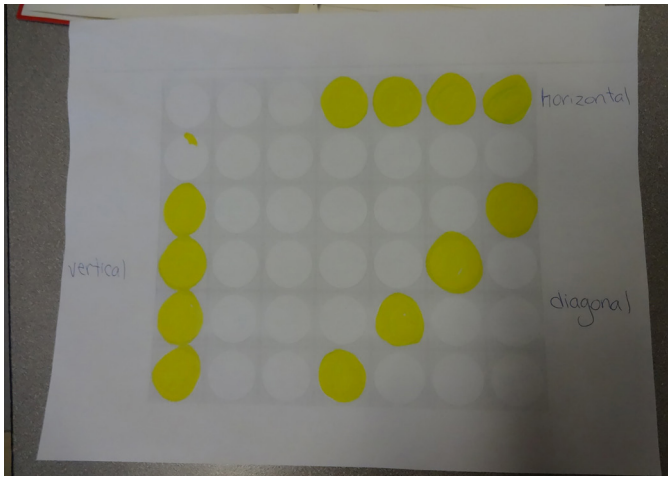


FIGURE 8. Connect 4 game board with mathematical vocabulary.

Once the children were familiar with Connect 4 and satisfied with playing in their own ways, we began talking about our thinking while playing the game. I encouraged them to talk as they played (that is, to think out loud). This led to their play becoming more purposeful, allowed for more observation and documentation of their understandings, and began shaping their strategies for playing the game.

Brainstorming New Rules

When considering how Connect 4 could be redesigned, I intended to listen to the students and allow the redesign concept to come from them. Being present with a small group of children playing the game allowed me to make observations, ask questions and document their experiences. I watched for any changes they might make to the game on their own. I did not have to wait for long.

During table centres, groups of children were playing Connect 4. One child didn't have a partner because he kept winning against everyone. So he decided to play the game by himself. After a few minutes of dropping chips of alternating colours into the grid, he declared, "I just won against myself!" A few children and I laughed after hearing that, since by having control of both colours of chips, he had, of course, allowed one colour to make a winning line. We used elements of this discovery in our Connect 4 redesign.

Redesigning and Playtesting

We played around with this concept of Connect 4 as a one-player game, keeping all other rules in place. Players were to play one chip at a time, alternating colours, and the way to win was to form a vertical, horizontal or diagonal line with four chips of the same colour.

I gave the children a paper copy of the Connect 4 grid so that they could document their game play by recording the moves they made with the red and yellow playing chips. This became the answer key. As an example, the key in Figure 9 reads as "Yellow goes first, with 11 moves, and red must win." The balloons (three circles connected with lines) indicate the celebratory winning.

FIGURE 9. One kindergarten student's answer key for one-player Connect 4.

In this process of redesigning and playtesting, the children encountered the concept of cardinality and ordinality of numbers. In other words, they counted the number of red and yellow chips on the board, but they also counted the order in which the chips were placed.

Creating Rule Books

Creating rule books went along with playtesting the new game. The students realized that it was difficult to remember which playing chip they had placed first, second, third and so on. They also realized that various arrangements of the playing chips could all result in a given colour forming a winning line.

This led to their making starting cards with a limited number of playing chips coloured in on the paper grid. The remaining chips were placed on instruction cards that told the player which colour to start with and how many moves were needed to make a given colour win. (See Figure 10.)

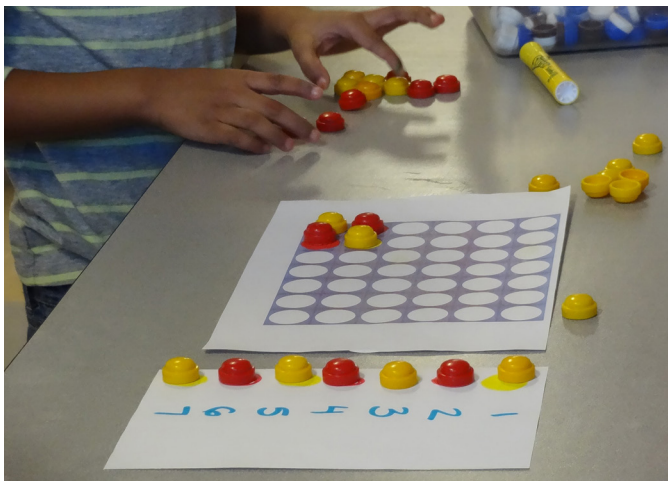


FIGURE 10. A kindergarten student playing with a starting card (top) and an instruction card (bottom).

Creating Good Copies of the Game

I laminated the starting cards and the instruction cards that the students and I had made together. These became the good copies that we kept so that we could play our redesigned Connect 4 game over and over.

Showcasing Our Game

The students shared their game cards with each other to play in class. We showcased our redesigned Connect 4 game at a math night so that students' families could see our work.

Conclusion

This article highlighted learning opportunities that fostered early numeracy by introducing narratives from a kindergarten classroom and a Grades 3/4 classroom in a linguistically diverse school.

These narratives depict how children used and demonstrated their understanding of integrated numeracy (including subitizing, understanding ordinality and cardinality of number, the area model of multiplication, spatial reasoning, and problem posing and problem solving). These various aspects of early numeracy were integrated and emerged under the goal of board game play and redesign.

The children were engaged in holistic learning throughout this process. They developed early numeracy through play and design, and they formed a positive relationship with mathematics by creating games that they themselves enjoyed playing and that they were proud to share with their families. Moreover, the social aspects of game play and redesign allowed them to talk about and create social rules for playing games and to position themselves as designers, problem solvers and creative people.

Notes

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1. See https://education.alberta.ca/media/159477/numeracy-definition-poster-colour.pdf (accessed October 11, 2019).

2. Gord Hamilton's website (http://mathpickle.com/puzzles-and-games/) has a range of puzzles and games that are highly relevant to mathematics learning (accessed October 11, 2019).

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