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Indigenous Pedagogy for Early Mathematics: Algonquin Looming in a Grade 2 Math Classroom

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Abstract

In this study we explored the connection between Algonquin ways of knowing and Western mathematics found in current math curricula. We used a cyclical research design of consultation, co-planning, co-teaching, and co-reflection to explore the potential of grounding Grade 2 mathematical instruction in the traditional Algonquin activity of looming. Results suggest the experience supported students' mathematical thinking including number sense, patterning, and spatial reasoning. We also discuss the implications of connecting two knowledge systems, the importance of engaging Indigenous community members in the teaching and learning of mathematics, and the power of engendering positive relationships with meaningful mathematics.

This article is based on an ongoing long-term project in which we collaborate with Elders and community members from different Indigenous communities across Ontario, Canada to explore connections between Indigenous and Western ways of knowing mathematics. The goal of this project is to explore mathematical content knowledge based on the Ontario curriculum expectations and the mathematics inherent in Indigenous cultural practices, pedagogical knowledge found in evidence-based teaching pedagogies founded on the principles of reform math instruction, Indigenous ways of teaching and learning, and contextual knowledge based on students' lived experiences in the community and how these connect to the context of a provincially funded public school.

The primary focus of this project is the exploration of bringing together two ways of knowing – the 15th century European-based mathematics found in the Ontario curriculum and the ways of knowing that evolved on Turtle Island prior to contact, but which have historically been excluded from the classroom. Ministries of Education across the country have recognized the need to explicitly incorporate Indigenous content to support identity building and appreciation of Indigenous perspectives and values. Access to the same curriculum as non-Native peers does not mean that the education Indigenous students receive is equal in terms of its alignment with cultural identity. There is a need in contemporary education to understand how to provide Indigenous students with a meaningful connection to their learning. Although in recent years work has been undertaken to incorporate First Nations, Métis and Inuit perspectives in curriculum subjects such as social studies, it is our belief that Indigenous perspectives should permeate all curriculum content, including mathematics.

The work outlined here was conducted in a Grade 2 classroom at a small public school near Pembroke, Ontario. The school population comprises approximately 20% Algonquin students from the nearby Algonquins of Pikwàkanagàn First Nation, and 80% non-Native students. In this work we have explored ways of bringing together community and school in support of mathematics learning, with a long-term goal of transforming school-based education from a colonial past into a form that respects both Western and Indigenous traditions. The Renfrew County District School Board encompasses traditional Algonquin lands, and the Algonquin people and their ancestors have been on these lands for between 10,000 to 20,000 years (Whiteduck, 2002). We believe that their knowledge not only contributes to Algonquin students' education but also can and should inform educational practices more widely.

Ethnomathematics and Culturally Responsive Mathematics

Current math instruction reflects a Western worldview dating back to 15th century Europe (Bishop, 1988). Research suggests that Aboriginal students view the mathematics taught in school as having no meaningful connections to their lives (Barta, Jette, & Wiseman, 2003). Ethnomathematics is a theoretical framework that has generated a growing area of research of how math curricula can and should respond to local culture (D'Ambrosio, 2006; Knijnik, 2002). From the ethnomathematics perspective, school mathematics is one of many diverse mathematical practices and is no more or less important than mathematical practices that have originated in other cultures and societies (Mukhopadhyay, Powell, & Frankenstein, 2009). Ethnomathematics provides a foundation for developing culturally responsive education, which refers to efforts to make education more meaningful by aligning instruction with the cultural paradigms and lived experience of students (Castagno & Brayboy, 2008). Making connections between math instruction and Indigenous culture has had beneficial effects on students' abilities to learn mathematics (Cajete, 1994; Lipka, 1994). Long-term studies by Brenner (1998), Doherty, Hilbert, Epaloose, and Tharp (2002), Lipka (2002), and Lipka, Sharp, Adams, and Sharp (2007) found that culturally responsive education in mathematics had statistically significant results in terms of student achievement. Recent researchers have also explored the insights Indigenous epistemologies and practices provide for understanding ways of teaching mathematics (Barta & Barkley, 2001; Barta et al., 2003; Battiste, 2002, 2004; Hampton, 1995; Leavitt, 1995; Nielson, Nicol, & Owuor, 2008). While these studies suggest that Indigenous pedagogical approaches benefitted both Indigenous and non-Native students' mathematics learning, few studies focused specifically on connecting Anishinaabe and Western mathematical perspectives.

Elder Stephen Kejick of Iskatewizaagegan First Nation (Shoal Lake #39) spoke to us during an interview in 2012 of the importance of numeracy in a traditional Anishinaabe knowledge framework, specifically by providing the individual with the ability to make sense in traditional contexts to traditional structures or items, which must be precise to demonstrate honor and represent meaningful purpose. The precision needed to create cultural artifacts, such as Ojibway beadwork, reveals the cultural importance of mathematical thinking. Kejick also spoke of the complexity of the number system, which predates European contact:

> The number system was placed here long before Columbus. The number system was already in place. How I get to know that is through my ancestors, my grandfather, and my great grandfather. And that's been sort of passed on from generation to generation.

In spite of the rich Anishinaabe mathematical history, there is a paucity of culturally relevant mathematics materials in school districts currently servicing children from Anishinaabe communities in Canada.

The National Council of Teachers of Mathematics (NCTM) articulates the necessity for all students to make connections between mathematics and real-world applications (NCTM, 2000). Reform-based mathematical teaching practices are aligned with many aspects of Indigenous teaching in that both emphasize experiential learning, modeling, collaborative activity and teaching for meaning over rote memorization and algorithm efficiency. Numeracy knowledge and skills found in this contemporary approach have the potential to respond to the needs of Indigenous students through incorporating traditional cultural activities. In addition, incorporating Indigenous epistemologies and perspectives aligns with other researchers (Harris, 1991) who advocate placing less emphasis on numbers and algorithms, and more emphasis on spatial reasoning, geometry and measurement, which are more relevant within Indigenous cultures than number or arithmetic. This shift in emphasis is mirrored in current mathematics education foci, which have shifted to the importance of spatial reasoning (National Research Council, 2006) and algebraic reasoning through patterns (Beatty & Bruce, 2012; Rivera & Becker, 2011) as foundational for the development of mathematical thinking.

Research Team and Design

One of the dangers of working as non-Native researchers within Indigenous cultures is the risk of appropriation of culture. Cultural appropriation is the taking of Indigenous knowledge to use within a different cultural context, without truly understanding the cultural significance of the knowledge. It was important that our core research team was comprised of cultural insiders and outsiders. Team members included two Algonquin teachers (Jody Alexander, Aboriginal

Education Project Coordinator; and Michele Gaudry, Native Language Teacher) and Christina Ruddy, Operations Manager at the Pikwàkanagàn museum and cultural centre Omàmiwinini Pimàdjwowin (O.P.) and expert loomer. Our team also included non-Native teachers from the school (Anne George, Student Work Study Teacher; Heather McEwen, Grade 2 teacher; and Mike Fitzmaurice, Grade 6 teacher).

Interviews with the research team members revealed their commitment to fostering a more inclusive environment in the school for Algonquin students, and the importance of bringing more Algonquin cultural influence into the classroom. Jody spoke about her own experiences in education, and how she saw a minimal reflection of herself as an Algonquin student within the public school environment.

> I remember in the front hall there was a display case and it had a headdress and some moccasins and some beadwork and some birch bark baskets and things. But that was it. There weren't any books. If there were books about us I don't remember them. When I say us I mean Native people. I don't remember seeing any of them so that has been my goal – to make sure that the students here see themselves in school and see that they are part of our school community.

Jody articulated her belief in the importance of a culturally responsive curriculum and the importance of fostering pride in identity. "I think that the work that we will be doing will be important for the math and really important to the student identity. I love that the students are going to be proud of whatever comes out of our research."

Anne, a non-Native teacher, was working as a Student Work Study Teacher (SWST) and had focused her research on the experiences of Algonquin students in the school.

> We found out really three key things; one was learning how to listen. So how do we listen to our First Nations students? How do we respond to our First Nations students when they present thinking to us or when they present us with or approach a task or problem in a certain way, what is our response to that? We are also hoping to explore more this year, for example, how do we nurture that learning spirit?

Anne agreed to be part of the research team because, as she states, "I hope to be closer to the community and my students, the students in this school. That's my biggest hope, that I hope to engage in learning at Pikwàkanagàn with students and I hope too, that we can create something."

Heather McEwen, the Grade 2 teacher, spoke about her interest in bringing Algonquin ways of knowing into the classroom, and was excited to investigate how to integrate new ways of thinking. "This is a gift for me to be able to be on the experiencing end, to be part of something. It's going to be great for the kids – bringing the community into the classroom."

In addition to creating a team of cultural insiders and outsiders, we used a cyclical approach as a framework for the project, which ensured that we continually cycled back to members of the Algonquins of Pikwàkanagàn community for guidance and feedback.

Consultation

As a team our first priority was to meet with key members of the Algonquins of Pikwàkanagàn community who were invited to share their insights and provide guidance for the project. Three Elders agreed to participate in an initial meeting: Jane Commanda, Howard Bernard, and Shirley Kohoko. During our discussion they recounted some of their own educational experiences. Jane spoke about how maintaining her identity as an Algonquin student was a struggle:

> My school years were a fight to be who I wanted to be and lots of the children – they had the same fight. They wanted to be Indian. They didn't want to be White, they wanted to be who they were. They didn't want to be nobody else and they couldn't let us be who we are and just teach us.

They also spoke about the need for Algonquin children to be able to navigate between two worlds, Pikwàkanagàn and the dominant Western culture. Howard shared the advice he received from his father as he prepared to leave the community and enter the wider world:

> "You come from a great era or a great place in time… or from a great people. You have that culture. Take it with you and get out there and take the best of it and the best of the cultures that are out there and marry the two of them together and make them work for you." So this is what I did and it has paid off, I think.

This reiterates the perspective that one culture should not be perceived as superior to another, but that both have strengths. This echoes the theoretical concept of the "third space" (Haig-Brown, 2008; Lipka et al., 2007) – creating an approach to education (and to life) that is not solely Algonquin, or Western, but is a hybrid of the two that combines the best of both worlds.

During our discussion, the advisors told us of their ongoing work to revitalize Algonquin culture and language in the community. Shirley spoke about the focus of the community of regaining traditional knowledge and cultural practices.

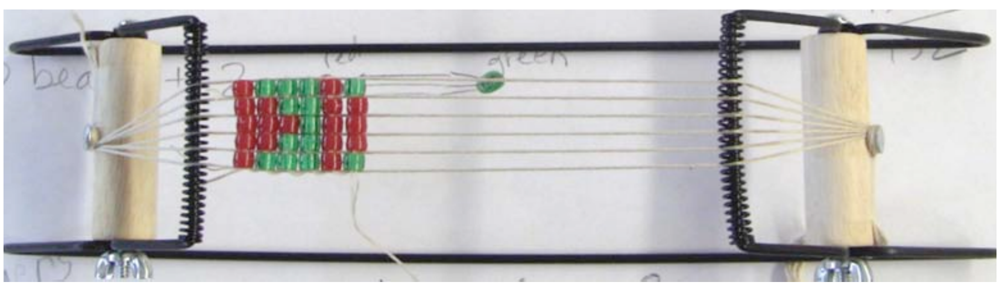
> From the outside it's perceived that we have all the culture. We don't. Culture was taken from us. We are actually in the process of *learning* our culture again. That's all historical stuff. I find that so intriguing right now. Cause I'm just learning that now too. Who are we and how did we get here?

It is important to note the distinction between the culture being *lost*, and the culture being *taken*. Like most Indigenous communities in Canada, the Algonquins of Pikwàkanagàn were forced to abandon many cultural practices, which they are now currently in the process of reviving. This focus on cultural revitalization in the community is something the advisors believed should be reflected in the students' experience in the classroom.

From a pedagogical perspective, the advisors spoke about the importance of providing hands-on experiences when learning, and the importance of making connections between children's experiences at home and in the classroom so that parents could better support their children's learning.

Planning: Exploring the Mathematics of Looming

The second phase of our cycle was to work with Christina Ruddy to learn the art of loom beading in order to explore its mathematical potential. As the name implies, looming is a type of beading that is done on a loom, and involves stringing beads onto weft threads and weaving them through warp threads.



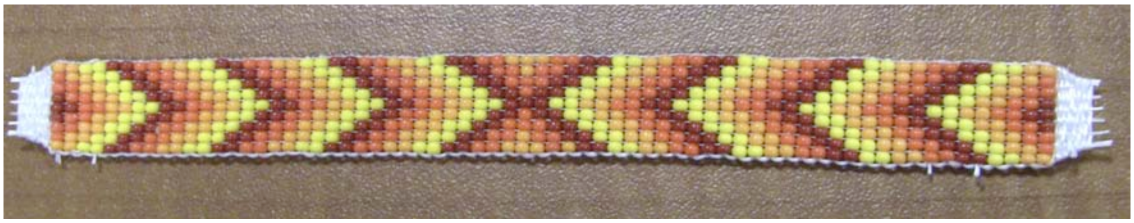
Christina discussed the historical importance of looming:

> The reading that I have done on the bead looming is that traditionally before contact and everything this would have been done with sinew and porcupine quills that were dyed. So that is the difference then to now – now there is glass beads and thread and everything but traditionally it would have been done with the sinew and porcupine quills. Because I questioned whether it was traditional craft or not, a pre-contact craft, and so when I did my research I discovered that, yes, it was there pre-contact.

Christina explained that the art of looming is inherently mathematical. She also spoke about her online research to learn looming techniques and to find traditional patterns:

> On the graph paper I design by color. And from there it is deciding your width (the width of the piece determines the number of warp threads – see Fig. 1) and so you count your beads, how long and how wide you want it. There's a lot of counting. So these [bracelets] are 9 beads wide. So then you have to know that you need one extra thread on the loom for every count of beads that you do. For example, a

bracelet that is 9 beads wide will need 10 warp threads on the loom. Then you have to measure your wrist and decide how long your bracelet needs to be – how many beads long. And for my designs – I like using an odd number of warp threads. Cause then you have a line of symmetry. Having one central line means you can make it symmetrical. And sometimes I find old patterns online, and I print them and try to figure out how they work.



Christina taught us how to design patterns for the loom. The pattern for each looming project (usually a bracelet) is created on graph paper (see Fig. 1). The first step in creating a design is to define the space to be used. The columns represent the weft threads, and the number of columns corresponds to the horizontal length of the beadwork. The rows represent the warp threads, and the number of rows corresponds to the width of the beadwork.

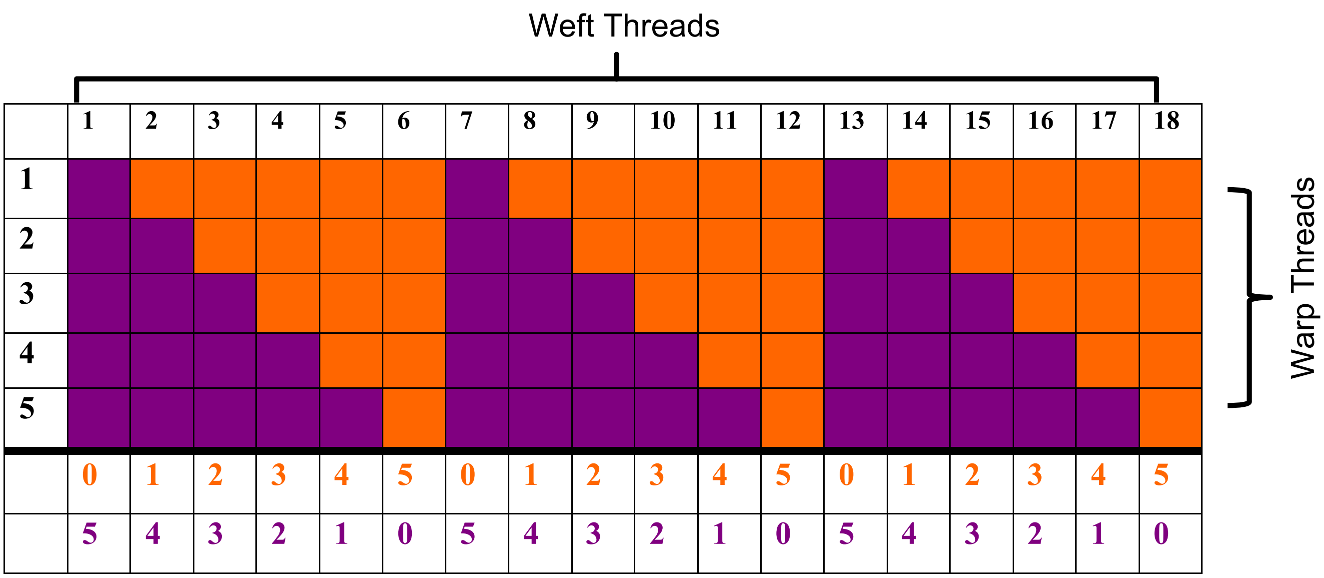


Figure 1. “Down the Stairs” loom pattern

The rows and columns of the design space are numbered. Below each column, the number of each color of bead is entered (with the number representing the color of the beads, in this case purple numbers for purple beads and orange numbers for orange beads). This helps the person beading to know the order for stringing beads for each column, or line of beads on the weft thread. Each column should add to the total number of beads on each weft thread (so in the example in Fig. 1, each column should add up to 5).

The horizontal and vertical grid, the 2-dimensional patterns created within the grid, and the visual and numeric patterns represented by the design, encompass powerful mathematical concepts. As Christina taught us how she views patterns and her process of design, we identified the potential for exploring number sense, spatial reasoning, and patterning and algebraic reasoning. As a group the research team developed a sequence of six lessons – three lessons focused on creating a pattern, and three focused on teaching students how to loom.

The patterns for the Grade 2 lesson were influenced by Christina's geometric motifs, and designed to allow students to explore challenging mathematical concepts. For example, the "Making 5" or "Down the Stairs" pattern shown in Fig. 1, was designed to illustrate specific concepts in number sense and numeration – part-part-whole relationships, compensation, equivalence, commutativity, as well as illustrating number facts for making 5. As the pattern progresses left-to-right from the first column, one purple bead is taken away and an orange one is added in its place. This illustrates not just the basic facts for making 5 (part-part-whole relationships), but also the idea of compensation – that is, to maintain 5 beads if one purple is taken away, then an orange one must be added; if 2 purple are taken away then 2 orange must be added, etc. This is reflected when looking at the numeric patterns (vertically the numbers represent ways to make 5, horizontally the two rows of numbers illustrate the idea of compensation – as one set of values increases by one the other set decreases by one). This pattern also illustrates the ideas of commutativity and equivalence (4 purple + 1 orange = 1 purple + 4 orange). Algebraically both the colored squares (representing beads) and the numbers reveal a multitude of patterns. For example, in this pattern the pattern core comprises six columns (columns 1-6, columns 7-12, etc.) and repeats every six columns. The core is composed of two "triangles" and each triangle is made up of 15 squares (5+4+3+2+1). Spatially the two halves of each pattern core are congruous, with the orange section representing a 180° rotation of the purple section.

The second pattern, "Down the Stairs, Up the Stairs" (Fig. 2) was an extension of the "Down the Stairs" pattern.

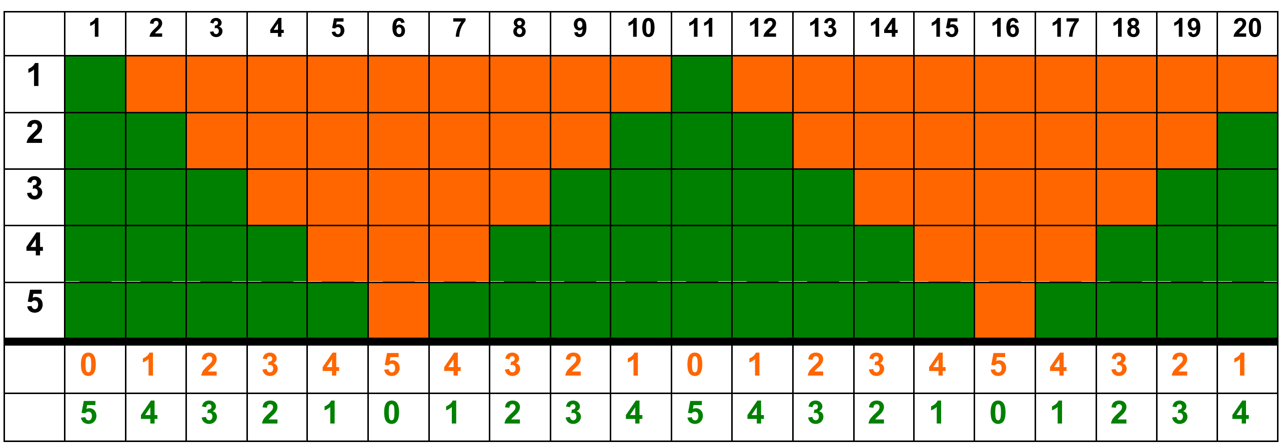


Figure 2. "Down the Stairs, Up the Stairs" pattern

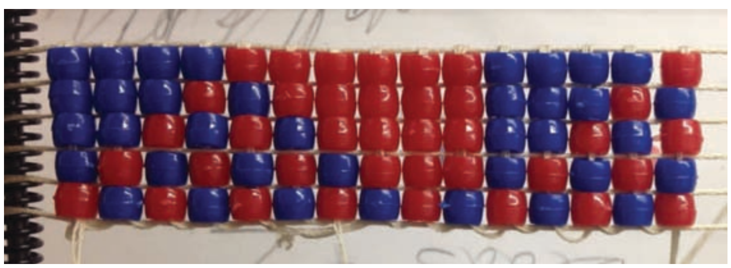
Teaching

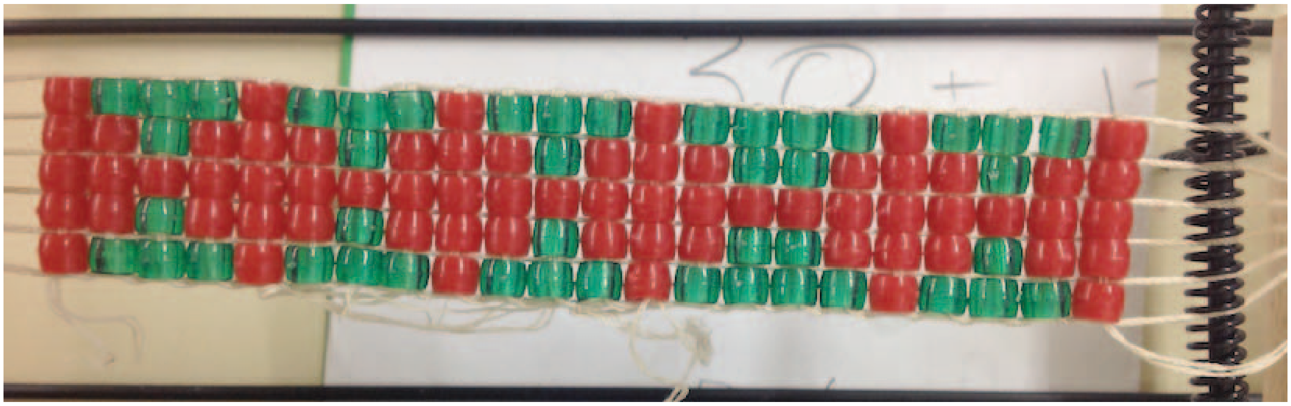
It was imperative that Christina taught the lessons in the classroom so that the Algonquin content could be taught effectively, passionately, and authentically. The module for the looming lessons included three lessons centered on designing a pattern, and three lessons teaching students how to loom. The first three design lessons took one week to teach, and the looming activity to create their bracelets took another week. Christina began by talking about the history and cultural importance of looming:

> Looming is something that has been done a long time – many years – pre-contact. But before there was beads and before there was all this wonderful colorful stuff, looming was something that we would do with quills. Quills would be died and cut down and they would be loomed with sinew from different animals. And I love the history part of looming and there's so many ways that you can do it.

Students were asked to copy and extend the two patterns onto their own paper template (Fig. 1 and 2). The template was 20 columns long and five rows wide. Copying the pattern onto the paper template first allowed the students to get a sense of the space they would be working within – a space delineated by a grid of rows and columns. Once students had designed their patterns using the paper template, they then used manipulatives to further explore their patterns. Through the process of filling in the paper template and then completing the concrete models, the students began to notice characteristics of the pattern. For example, many students quickly realized that the pattern was a repeating one and that the first six columns represented the unit of repeat, or pattern core.

The students then created their own patterns, which they used to construct their loomed bracelets. Although the students had been explicitly taught two patterns, they created a variety of original designs.





At the end of the module, once their first projects had been completed, the students were taught how to string a loom. This final step meant that all students became self-sufficient loomers and could design a pattern, string a loom, and loom their beads. They continued to create designs and use their looms in the classroom at different times for the rest of the school year.

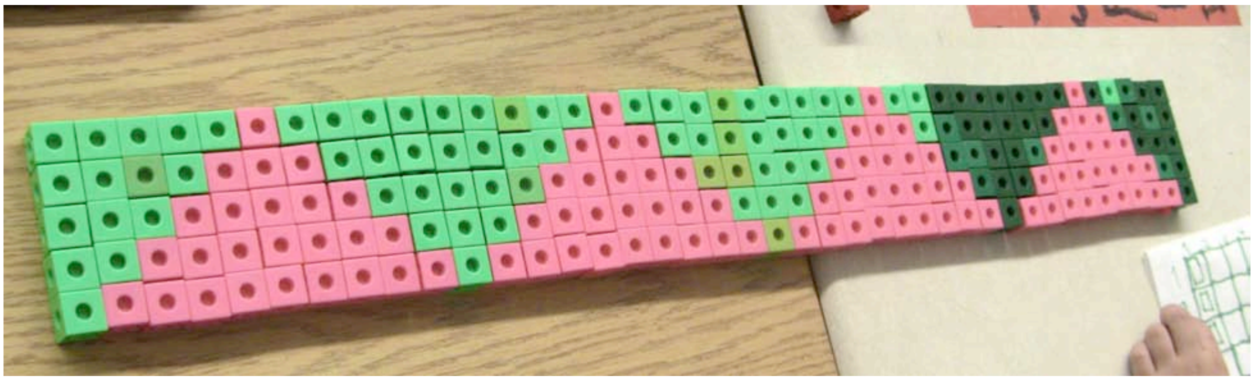
Reflecting: Looming as a Catalyst for Mathematical Thinking

As a group, we watched and analyzed video recordings of in-class lessons to identify the mathematical thinking that surfaced during classroom conversations. This process of co-analysis involving Algonquin and non-Native teachers and university faculty ensured that our focus was both on the students' mathematical thinking and the cultural connections.

The process of copying, extending, and creating the pattern using different 2-D and 3-D models resulted in rich mathematical explorations. The examples given below illustrate some of the mathematical thinking captured in the Grade 2 classroom during the pattern planning and looming stages of the project.

Multiplicative Thinking and Spatial Reasoning

Students Kayla and Lyle used multilink cubes to extend the “Down the Stairs, Up the Stairs” pattern to 41 columns long. Each cube represented one bead.



They calculated the number of cubes in their pattern by noticing that each column was made up of 5 cubes. They skip counted by 5s to 100 [20th column] and skip counted again by 5s to reach another 100 [40th column]. Once they calculated the number of cubes for 40 columns, Kayla explained, “There was one column left. And 100 plus 100 is 200. And 5 left is 205.”

When asked how many pink and how many green beads they would need if they were to loom the design, Kayla at first suggested counting by 5s, starting with the columns that had 5 green cubes. Lyle suggested counting by groups of 25 because in each of the pink pyramids there were 25 cubes. The two students counted the four pink pyramids by 25s to determine there were 100 pink cubes altogether. When it came to finding out the number of green cubes, the students counted the three full green pyramids and came to a value of 75. When thinking about the half pyramids at each end of the pattern, Kayla thought that they could put them both together to make a full pyramid because, “if it was a circle, these two would be together and make a full pyramid.” Lyle agreed, but after looking at the design more closely, Kayla realized that this was not entirely accurate.

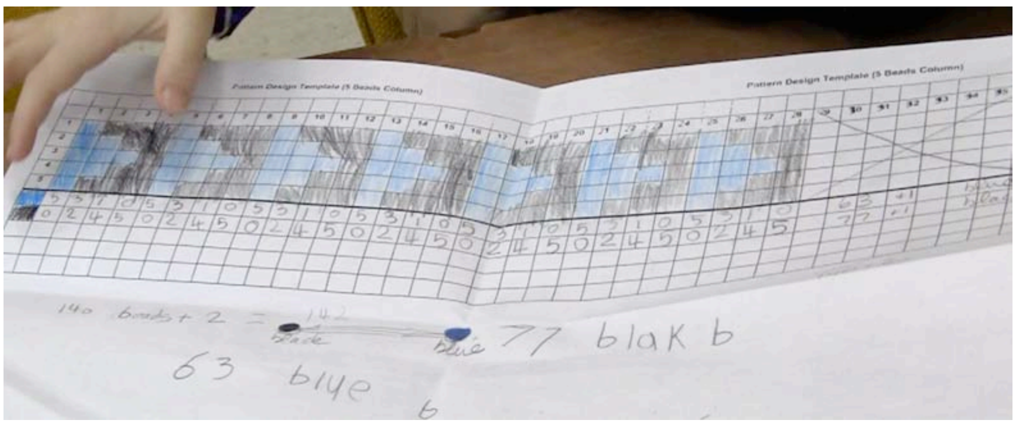
> Because it would almost make a full pyramid if we put these in a circle. Except it wouldn't be! Because it’s two lines! Because there’s a line there and there [the half-pyramids on each end both contained a column of 5 green cubes] and there’s only one line of 5 [pointing to the central green column on a full pyramid].

Kayla realized that if the two halves were put together (if the pattern was formed into a circle so that the two ends met) there would be an extra column of 5 green beads in the middle of the pyramid. She reasoned that there were 105 green cubes altogether, “because it’s just like what I just said. There’s two lines. If you take off one of these [column of 5 green beads] it would be 100 green beads.”
Kayla and Lyle grouped their cubes into units to make the counting easier. This ability to create and conduct operations with groups of objects indicates that the students were unitizing, an important component of multiplicative thinking. Unitizing is the ability to simultaneously consider a group as both a single entity (one group) and as the individual objects that make up the group. Kayla began by creating groups of 5 cubes, and then skip counted by 5s to get the total. Lyle counted 25 cubes in each pyramid and used that as his unit of repeat. When it came

to counting the two half-pyramids on the end, Lyle initially assumed that since each end appeared to be half of a full pyramid, that the two together would get a count of 25. However, Kayla was able to mentally manipulate the pattern, bringing the two ends together to create a "circle" and visualized the resulting pyramid, which would have an extra column of 5 green cubes in the middle. This ability to imagine the movement of structures in space as a way of problem solving is an example of spatial reasoning, another important component of mathematical thinking (Mix & Cheng, 2012).

Number Sense, Multiplicative Thinking

One of the tasks given to the students was to determine the number of beads they would need for their bracelets – both the total number and the number of each color. Dan designed an "Arrow" pattern. This design was based on the "Up and Down Stairs" pattern, which Dan rotated 90° and then reduced to fit his template. His final design was 28 columns wide (7 arrows).



To determine the total number of each color bead he would need, Dan figured out the number required for each of the pattern cores – the core was represented by the first four columns of the pattern. He added up the number of black beads and then the blue beads in each pattern core, and then added these totals 7 times (since there were 7 iterations of his pattern core). To figure out the number of black beads needed, Dan paid attention to the numbers recorded below each column and added up the total number of black beads recorded in the first four columns (0+2+4+5). As he added, he made use of a "making 10" strategy, adding up 2+4 first to get 6, then taking 4 from the remaining 5 to make 10, and the one remaining to total 11 (2+4=6, 6+4=10, 10+1=11). He then added 11 a total of 7 times.

RB: So tell me how you added the black beads.

Dan: I added up 2 and 4 that would be 6. Then 6 plus 4 would be 10, then 1s left from the 5 and then that would be 11. First of all I added up the 11. And 11 plus 11 would be 22. And then another 11 would be 33. Then another 11 would be 44. And I kept on adding up 11s that totaled up to 77.

To add up the blue beads, Dan first added the total number in one pattern core, which equaled 9. However, instead of finding out the total for 7 groups of 9 beads, Dan then found the number of blue beads in two pattern cores, and added 18 three times, and then added 1 more group of 9 to find the total for 7 groups of 9 beads. His description of the processes he used to add his numbers reveals his computational fluency.

RB: What did you do for the blue beads?

Dan: I add up 5, 3, 1 and 5 plus 3…would be 8 and then 1 more would be 9. Then I added 9s, I started with 9 and then added 5 to get 14 plus 3 that would be 17 plus 1 is 18 so I took those and I kept on adding up 18s. That equaled 63.

Dan checked his work by finding the total number of beads for his pattern. He added 63 (blue beads) and 77 (black beads) for a total of 140. To check that this was correct, he added groups of 20 beads 7 times to get 140 beads total. He created the group of 20 by adding the 11 black beads and 9 blue beads found in each pattern core. As he described it, he initially focused mainly on the numbers he was working with. We asked him more questions to ensure he was connecting the numbers with the pattern he had created.

Dan: Here's 5 blue then 3 then 1 [pointing to the colored squares in the arrow pattern] so 5 plus 3 would be 8 then plus 1 would be 9 blue in this. Then 2, 4, 5 [pointing to the numbers] that would be 2 plus 4 would be 6, then I take 4 from 5 that would be 10, then 11. And since there's 9 in the other one, take that

1 from 11 and put it on the 9 then get the 10, and then 10 plus 10 would be 20 and then you keep on getting that 20.

DB: Can you show me where the 20 beads that these numbers represent, where they are in the blue and the black up here?

Dan: Like the 9 beads are always these arrows and the 11 beads are always in this [the black surrounding the arrows] so I take this [the arrow and the black] and then that's a 20, 40, 60, 80, 100, 120, 140 [pointing to the units of 20 along the pattern].

This exchange demonstrates Dan's growing facility with numbers. He created units of 11 and 9, and then added those using a compensation strategy (take 1 from 11 and give it to 9 to make 10 plus 10). This is another example of a student constructing an understanding of unitizing. Dan was able to unitize the blue and black beads within the pattern core, as individual units of 9 blue or 11 black beads, and as a larger unit of 20 blue and black beads. Dan used both the visual and numeric groups to be able to create and work with these units.

Patterning and Spatial Reasoning

During the course of designing their patterns and then constructing them on the looms, we discovered that students were able to work with their patterns on three levels; 1) the overall pattern of the bracelet; 2) the relationship of each column to the previous and/or next column; and 3) the relationship of the beads within the column. We also discovered that students internalized the structure and sequence of their designs through the process of beading. For example, Chris designed a diagonal pattern using five colors (Fig. 3). As he was beading, he stated that after the 8th column he no longer needed to refer to the paper template because he had memorized the sequence of the colors of his pattern – orange, red, yellow, blue, green.

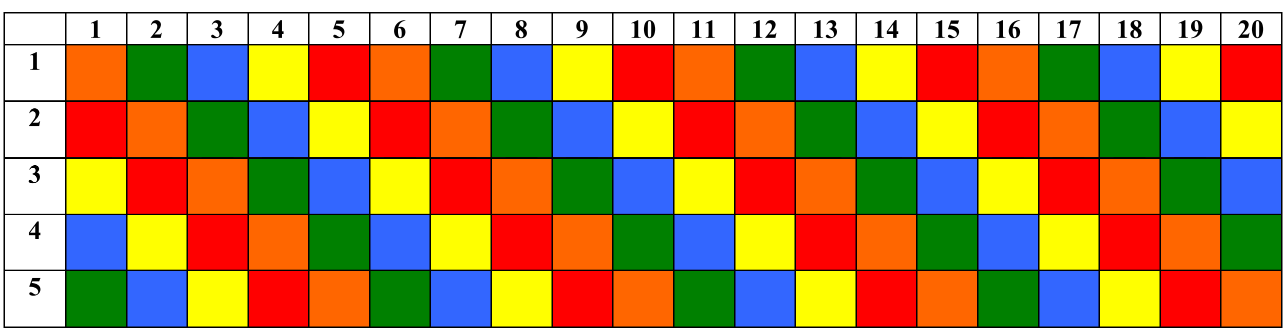


Figure 3. Chris' diagonal pattern

If Chris had simply strung the five colors of his repeating pattern on each weft thread, however, the result would have been horizontal lines (Fig. 4) because his pattern was a repeat of five colors on a five-row template.

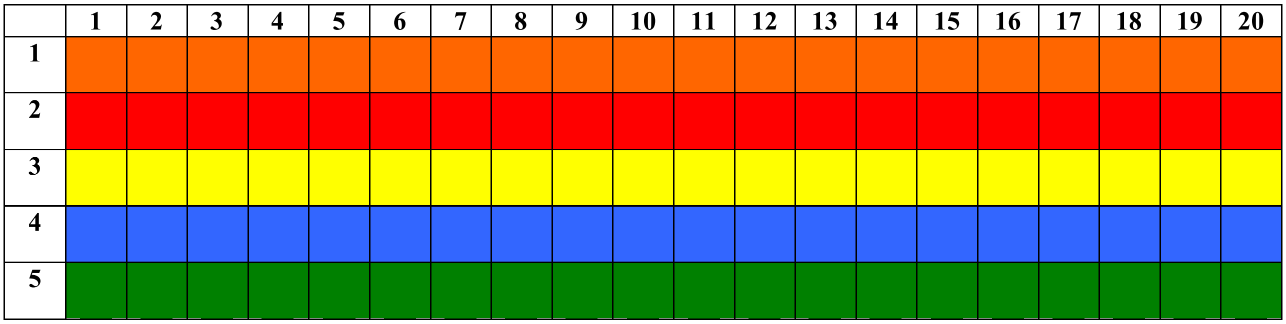
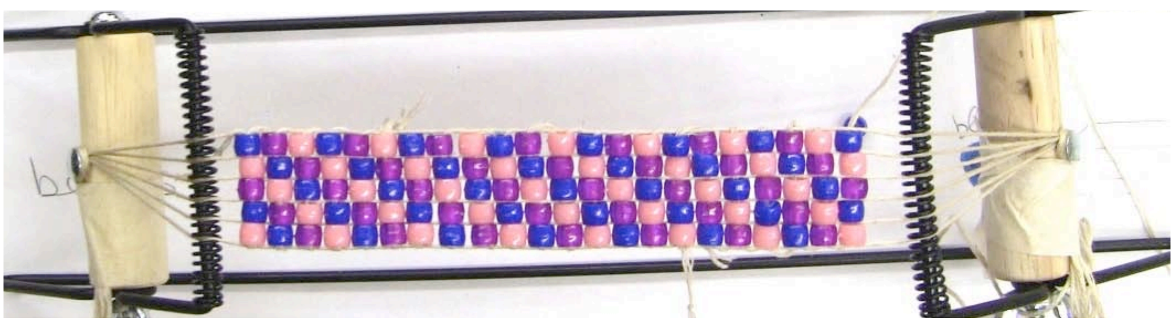


Figure 4.

In order to create the diagonal lines, Chris reasoned that the color of the bead at the bottom of each column would need to be repeated at the top of the next column. This caused the colors to shift down 1 bead each time, creating a diagonal pattern. Chris focused on three levels of his pattern – the sequence of his repeating five-color pattern by column, the relationship of each column to the previous and the next column, and the resulting overall diagonal pattern.

Like Chris, Lexie also designed her pattern by repeating a sequence of colors down each column. Her sequence comprised three colors – blue, pink, purple. She discovered that a three-colour repeating pattern, repeated vertically on a five-row grid, resulted in diagonal lines. This is because 5 is not a multiple of 3 (or 3 is not a factor of 5) so the 3-bead pattern core could not be neatly repeated within a 5-bead space. Part of the core had to continue onto the next column.



Lexie: Because it's five rows and my pattern is three colors. So I put blue, pink, purple, blue, pink [down the first column] so it's like a pattern. And I kept going on and I saw that it was going like lines [gesturing diagonally] and I started making those lines.

RB: So you were repeating the blue, pink, purple but you were doing it down each of the columns each time.

Lexie: [Nods]

RB: And so what happened to your lines?

Lexie: Then they started going diagonal!

RB: I have a question for you, why do you think it did that?

Lexie: Because then you go onto the next column, this one [the blue square from the top of column one to the second in column two] gets shifted down, then that one gets down and they keep getting shifted down each column.

RB: How come they get shifted down? Why do you think?

Lexie: Cause they're different patterns.
RB: What do you mean?
Lexie: That one [first column] is different from that one [second column] cause it starts with purple and that one's different from that one [third column] cause it starts with pink. Then it started going over again [by the fourth column the columns start to repeat].

Lexie identified that her 3-bead core could not be repeated in its entirety in the 5-bead space of the column, and so part of her 3-bead pattern core had to shift to the next column, and this shifting caused the diagonal lines in the pattern. However, her explanation also indicates that she noticed a second pattern in her design, the core of which was made up of the first three columns of her pattern. This larger core repeated every three columns, for example, columns 1-3 are the same as columns 4-6 (Fig. 5). This larger core is made up of 15 beads in total, which is a multiple of 3, therefore the blue-pink-purple core could be repeated five times in three columns.

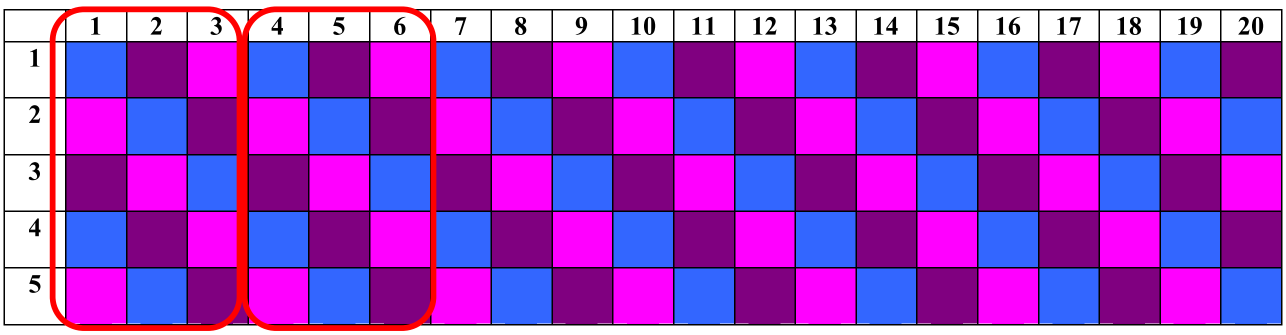


Figure 5. Lexie's pattern

If we think of the typical kinds of patterns students in Grade 2 are exposed to, they tend to be repeating patterns of the kind e.g., ABC ABC (blue, pink, purple, blue, pink, purple), which are usually presented horizontally. When analyzing their looming patterns, students coordinated their perceptions of multiple patterns that extended vertically and horizontally as well as diagonally, and incorporated spatial reasoning with algebraic reasoning. Lexie, for example, recognized her pattern core within each column (blue, pink, purple) but also identified the larger core made up of three columns. Chris amended his repeating pattern to add an extra repetition of color at the top of each column, thus modifying his ABCD pattern to something more complex, underpinned by his desire to create diagonal instead of horizontal lines. The students' reasoning drew upon both their growing understanding of the complexity of patterns and how these related to the spatial relationships created within the grid on the loom.

Further Reflections

In this sequence of lessons students were able to develop a number of key mathematical processes – specifically multiplicative thinking, patterning, and spatial reasoning. A key element to the teaching sequence was the numerous opportunities students had to communicate their ideas to one another. The lessons included direct instruction from Christina about how to use the design template, how to create a design, how to string a loom and how to loom bead. But once the instruction had been given, students were free to work individually or with partners and could choose to build with manipulatives or create designs on chart paper or on the paper templates. They tackled problems as they arose, for example, the number of beads they would need, how to fit their design onto the defined space of the template, and how to modify their designs to achieve diagonal patterns. When we analyzed the recordings of classroom talk, we found that student communication was always on task and nearly always mathematical.

Sharing: Bringing Our Work Back to the Community

During the course of the lesson implementation we invited members of our advisory group, and members of the wider community, to visit the classroom. In addition, we invited community members – especially parents of children in Grade 2 – to two evening gatherings in Pikwàkanagàn to review photographs, artifacts and video recordings of their children's experiences. We also produced an eight-page booklet outlining the project, which highlighted student thinking. This booklet was made available at the school, the Pikwàkanagàn cultural centre and museum, and at a booth during the summer powwow. The feedback from the community was overwhelmingly positive, and community members expressed pride in the mathematical thinking the children were demonstrating, and in the fact that their community practices were being highlighted as a way of engendering deep mathematical and cultural understanding in the classroom. Suggestions for future activities came with a wish to include more Algonquin language in the instruction. Pikwàkanagàn is a community that has experienced significant language loss, which community members equate with the taking away of culture and cultural identity. We plan to incorporate Algonquin language as part of the instruction during our second year of the project.

Discussion

Connecting Algonquin and Western Ways of Knowing Math

Ethnomathematics and culturally responsive teaching specify working within the mathematical systems established within a particular culture, in this case, the Algonquin culture of Pikwàkanagàn. However, as Shirley stated, this was a community that had much of its culture taken away. The connections that we made between Western and Algonquin mathematics took the form of creating a "third space" (Gutiérrez, Rymes, & Larson, 1995) in the classroom by exploring the potential of Algonquin activities for mathematics, and bringing Algonquin culture into the classroom. This third space, merging Algonquin and Western ways of knowing, is created when the knowledge and perspectives of traditionally excluded communities are privileged alongside the dominant society's pedagogy and content. The activities we chose were suggested by members of the community, and aligned with the community's stated commitment to revive these activities. The resulting learning experiences were a hybrid of Algonquin and Western cultural content and pedagogical approaches.

With respect to pedagogy, Christina incorporated expert-apprentice modeling and direct instruction in her teaching. Recently there has been a debate about whether mathematics instruction should center on the direct instruction and memorization of mathematical facts, or whether math should be a subject of inquiry and exploration. In our study, Christina incorporated cognitive apprenticeship into her instruction. According to Lee (1995), "in a cognitive apprenticeship, the goal is to make visible and explicit thinking strategies that experts use in particular domains" (p. 613). Christina explicitly told students how she used the template to design a pattern, and how she used the template to create her loom work. Nonetheless, these direct instructions were taken and individualized by each student so that they had to make sense of the task in a way that was meaningful for them and, consequently, learned a great deal of math content. Many of the directions given the students were specific e.g., how to use the template to design a specific pattern, how to numerically record the number of beads in each column, how to string a loom, etc. However, Christina also reiterated the fact that there were many ways to accomplish the tasks. For example, here are two excerpts from Christina's lessons:

> Ok. So if you were to start a pattern – the way that I start it, and everybody is going to do it different, this is what I've learned from working with your teachers on how to do this stuff, is that everybody started their project different than I did and than the person they were sitting next to and that's ok too.
>
> So there are a couple of ways you can do this from here on. I'm going to show you both ways and maybe you guys can figure out an easier way or you'll work from the way that I do it.

The final product was open to each student's choice of design and how s/he chose to execute the instructions. The process of making sense of the instructions, and the process of creating tangible products, resulted in students who were motivated and engaged in the activity and in the mathematical concepts inherent in the activity. Teaching by modeling, or direct instruction, does not have to result in surface-level learning through imitation. Instead of finding one "right" answer students explored multiple solutions and ways of completing the activity within the confines of the task.

Although Christina began each lesson by directly teaching students an aspect of the activity, once students were at the phase of designing their own patterns, or working on the looms to create their bracelets, Christina sat at a central table and students were free to work with her individually or in groups. Other students worked in their table groups, or in groups on the carpet. We noted a lot of peer-to-peer support as students helped one another both with the pattern design, with counting beads, and with the looming.

As previously stated, the students engaged in looming throughout the course of the school year, making three or four (or more) projects. It was important to provide students with these mastery experiences. The initial project outlined here was a chance for students to learn the basics of designing a pattern and creating a bracelet on a loom. The subsequent projects allowed them to refine their skills, to test out new ideas, and to explore more deeply the mathematical concepts that emerged. Heather, the classroom teacher, wanted each student to become a looming expert so that when the looms were sent home over the summer, "they wouldn't sit on a shelf gathering dust." When we returned to meet with students during the following September, they were eager to show us the projects they had completed over the summer. There was discernable growth in their designs and technique.

The lessons honored the important pedagogical aspects that Howard, Shirley and Jane had discussed during our first interview. The activities were hands-on and kinesthetic and had practical as well as mathematical implications. The loom patterns the students designed did not stop with their two-dimensional pattern templates. The students then translated these two-dimensional representations into three-dimensional cultural objects. By analyzing video recordings of student thinking, we found the process of looming was more cognitively demanding for students than mathematical instruction that prioritizes algorithmic memorization.

Importance of Engaging the Wider Community

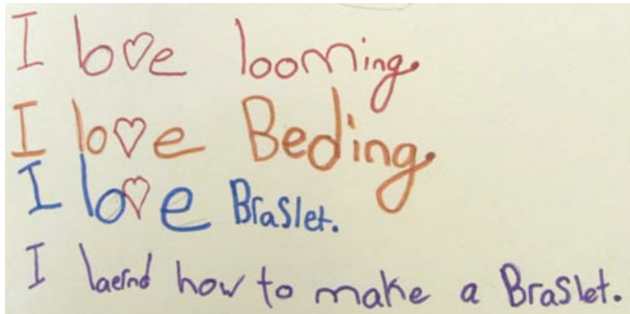
Throughout this project we have been aware of the generosity of Pikwàkanagàn community members and their willingness to share their knowledge with us. One of the most important reasons to invite members of the community to co-design and teach the activities in the classroom was to ensure that the activities were taught within the context of the culture. Christina taught the lessons with an emphasis on the cultural importance of the activity, which provided an opportunity for students from Pikwàkanagàn to connect their own cultural heritage alongside a reconceptualization of what it means to "do math." This reconceptualization was also important for the non-Native students who gained greater insights into the culture of their classmates, and who extended their own mathematical thinking.

One of the most important aspects of this project has been the focus on relationships both in the classroom and between the classroom and the community. As the project drew to a close, Christina reflected on the stronger relationships being forged in the classroom, with stereotypes stripped away and pride in identity supported.

> I know for you, you get excited by the mathematics. But what's so important for me is that we're working with all of the children – not just the Algonquin kids. It's important that the kids get to share with their non-Native friends. And having opportunities to talk about their regalia because of the beading, and that it's becoming normal. It's not mystic and it's not stereotyped. So for me this project is about something different. It's about taking away that division. It's good.

Engendering Positive Relationships With Meaningful Mathematics

Incorporating the looming activity created a purpose for students to engage in mathematical thinking. Math is in the doing. Teaching math through an activity like looming means that math is no longer external and abstract, but becomes internalized through actions. We conducted individual student interviews in June, eight months into the research project, and all students reported being excited to learn math through looming.



The experiences presented in this paper demonstrate ways of bringing local cultural knowledge that has been excluded from math instruction into the classroom. Although these lessons were designed primarily to address the needs of students from the Algonquins of Pikwàkanagàn First Nation who attend a provincially funded school, we believe they might be a useful example for other educators looking to incorporate Indigenous pedagogy and activities as a way of making learning both mathematically rigorous and culturally meaningful.

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