# How can we best use our school garden space?

## Exploring the concepts of area and perimeter in an authentic learning context

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Using Garden Based Learning (GBL) as an integrated mathematics and science unit, this article describes the mathematical journey of students as they work through the process of designing their own garden beds.

## Introduction

It is a sunny spring morning at Bartram Elementary School. When the bell rings, the 8- and 9-year-old students in Room 202 are buzzing with anticipation and excitement as they prepare to go outside and plant in their school garden. Learners have been strategically planning what they are going to plant in the class garden based on a question their teacher, Mrs Riley, posed earlier in the year: "How can we best use our garden space?" Today is the day that all of Mrs Riley's students' hard work and planning is put into action. The children remember the day that Mrs Riley first challenged them to use their knowledge and skills in both mathematics and science with the following challenge (Figure 1):

Since that time, the students have researched, discussed, and planned what they are going to plant in both their own garden regions and across all of the garden regions. Garden-based learning (GBL) was initiated at Bartram Elementary School in 2011, with educational partners utilising the GBL infrastructure to improve and integrate instruction in core disciplines (Rye, Selmer, Pennington, Vanhorn, Fox, & Kane, 2012). Recent reviews of the literature on GBL provide considerable support for its value, especially at the elementary level, in providing authentic experiences and achieving positive academic outcomes particularly in science, but also in mathematics and language arts (Blair, 2009; Williams & Dixon, 2013). The primary purpose of this article is to show how a GBL integrated mathematics and science unit centred on Mrs Riley's challenge question can be used to teach mathematical concepts of area measurement.

**Remember that we are trying to answer the question:**

**How can we best use our garden space?**

You will be working in teams of three or four to design a specific section of our two class garden beds. First, you have to decide how to divide up the entire garden bed into different regions for each group. Should each region be the same size or will some of the chosen plants need more space than others? You cannot just think about your own garden space; you also have to consider how your space will affect the entire garden. For example, if Karla's group chooses to grow sunflowers and your group chooses to grow radishes, what do you think you might need to consider when dividing the garden so that both plants flourish? Ms. Williams (the Principal) has asked us to try our absolute best to design a garden that will grow in the spring and last all summer long. We are going to have to think very carefully about how to design and plant a successful garden in our two beds.

Figure 1. Mrs Riley's challenge.

## Mathematical focus of the GBL experience

To learn area measurement, children must develop a notion of area as an attribute of a plane figure, including the understanding that decomposing and rearranging shapes does not affect their area. Students also develop the understanding that a square with a side length of one is a unit square, measuring area by tiling figures and counting the unit squares it takes to cover without gaps or overlaps. Students also develop the ability to build an understanding of two-dimensional arrays and then to interpret two lengths as measures of the dimensions of those arrays, and also relating area to the operations of multiplication and addition (Clements & Sarama, 2009; Wickstrom, Nelson, & Chumbley, 2015). Without such understandings, older students often learn a rule, such as multiplying two lengths, without understanding area concepts (Clements & Sarama, 2009).

Area concepts take students time and experience to work through and understand (Clements & Sarama, 2009). Further, researchers (Battista, 2007, Clements & Sarama, 2009) have shown when students first encounter area, they often find difficulty structuring square units in rows and columns. Students will leave gaps or overall area units as well as create units that are not each the same size. In response to these concerns, it has been suggested that students are allowed to use physical square units; a gardening environment provides students access to real-world physical units and tools, allowing for fluidity between many focused area concepts as well as a connection to the sciences (Wickstrom, Nelson, & Chumbley, 2015). Specific to the United States, because some U.S. customary units are common in real-world gardening contexts (e.g. raised garden beds are typically measured using feet), Mrs Riley adapts these situations using non-standard square units, to maintain her primary mathematical focus.

## The GBL experience

The GBL integrated mathematics and science unit can be implemented in various ways at different schools (e.g., for different lengths of time, modified activities). The following descriptions, related examples, and approximate timelines are one way to implement the learning experiences. After presenting the driving question, "How can we best use our garden space?" Mrs Riley designed and implemented classroom learning activities around additional guiding questions and real-world, contextual constraints as detailed in Table 1.

Table 1: Guiding questions.

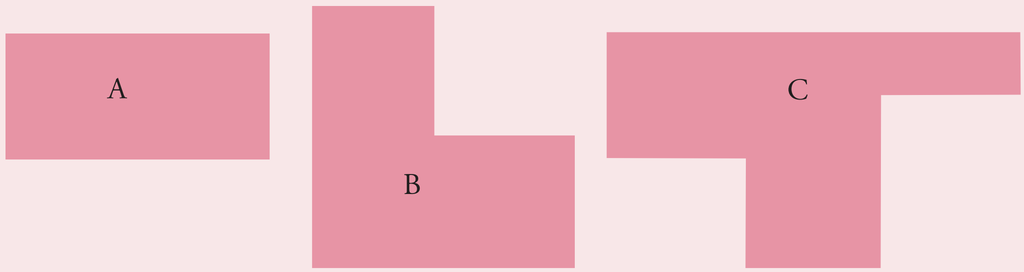
| GBL driving question: How can we best use our garden space?<br>Additional guiding questions and constraints | |
|---|---|
| 1) | **Constraints**<br>• The class has access to two garden beds.<br>• There are 10 learner groups that each need their own rectangular garden space.<br>• Groups can choose from 12 seed varieties based on seed availability. |
| 2) | **What will we grow in our gardens?**<br>Your group can choose from the following plants: radishes, parsley, basil, sunflowers, beets, onion, squash, watermelon, green beans, peppers, and kale. Thinking about what your group wants to grow, what should you consider about the other groups' choices? Why should you consider these things? How will these considerations make sure the entire class garden is successful?<br><br>What is your group planning to plant? Talk with other groups about their plans. Make sure each group considers its individual garden plot, other groups' garden plots, and the entire garden region. Remember that larger areas would be for plants that need more space for growth (e.g., squash) and the smaller areas for plants that are more compact (e.g., head lettuce). |
| 3) | **How will we divide our garden beds?**<br>The two garden beds should be divided into ten garden plots, so each group has a garden space. Your group should decide how to divide our class garden space taking into consideration what will be planted and the available space. |
| 4) | **How will each group use its individual garden space?**<br>Consider how the class chose to divide the two garden beds and what your group wants to plant.<br>Decide how your group will use its space. |

Based on the guiding questions in Table 1, Mrs Riley designed learning activities focused on developing core skills and concepts aligned to the mathematics and science of the GBL unit. (The emphasis in this article is on the mathematics.) Table 2 provides a description and timeline of these activities. Experiences culminated with the development and implementation of a plan for the outdoor garden space involving 10 group garden spaces growing a variety of plants.

Table 2: Guiding questions and related classroom activities.

| Guiding question | Related classroom activity | Timeline |
|---|---|---|
| | **Pre-assessment task**<br>Students designate their unit and determine the area and perimeter of three garden beds. | |
| What will we grow in our gardens? | **Research**<br>Students use varied media resources to learn the basic information about their group's chosen plant. Students research to determine the amount of space required, how to care for the plant, harvesting information, etc. | Week 1 |
| | **Mathematics and science journal entries**<br>Students work in their mathematics and science journals (complete problems using both non-standard and initial use of metric units, pose and answer questions, and reflect on classroom experiences). | On-going |
| How will we divide our garden beds? | **Measuring an indoor garden bed**<br>Teachers or students use the measurements of an outdoor garden bed to create a masking tape outline of the garden bed on the classroom floor. (Both outdoor garden beds are equivalent rectangles.) Students utilise this indoor garden bed representation and square units to determine the distance around the outside (perimeter) and the space inside the bed (area). | Week 2 |
| | **Initial group proposal**<br>Each group presents its proposal using square units for its garden space sharing what will be planted, the plant's needs, and an initial idea of how to organise their garden plot to meet the plant's needs. In planning, groups take into consideration both individual plots and the entire garden regions. | End of week 1 |
| | **Maths lesson focus on area and perimeter**<br>Provide students with background lessons (e.g. https://www.engageny.org/resource/grade-3-mathematics-module-4-topic-overview) to support their understanding of area and perimeter. Start with basic shapes and discuss the distance around the outside (perimeter) vs the space inside (area). | On-going |
| | **Develop a group proposal to divide the class garden beds**<br>Students use their plant (seed) research, their area and perimeter understanding, and their consideration of other group's needs to propose a plan to divide the two garden beds into 10 garden spaces using non-standard units. The students must take their research into consideration while deciding where to plant their seeds and how to organise the garden bed. | End of week 2 |
| | **Presentations**<br>Groups present their proposals for dividing the class garden beds. The class votes on the final plan that will be implemented. | Week 3 |
| How will each group use its individual garden space? | **Research**<br>Students revisit varied media resources to verify any further information they need based on the final design plan. Students also consider plant needs within their individual planting spaces. | Week 4 |
| | **Develop and implement a final planting plan**<br>Students put their plan into action as they create an outdoor garden space. The students partition their bed into the different spaces. Students use their knowledge about perimeter to mark the perimeter of their group's garden space for their plants. Then the students use their research to plant their seeds. | Week 4 |
| | **Post-assessment task**<br>Students designate their unit and determine the area and perimeter of three garden beds. | |

**Here is a plan for a school garden. The three areas show three garden beds.**




1. What is the area of shape A? Explain how you found your answer.
2. What is the perimeter of Shape A? Explain how you found your answer.
3. What is the area of shape B? Explain how you found your answer.
4. What is the area of shape C? Explain how you found your answer.
5. On the diagram above, draw a shape that has the same area as shape A.

Figure 2. Task 1 Adapted from the Noyce Foundation (2006).

## Assessment task

An assessment task, as shown in Figure 2, was administered prior to and after the students engaged in the classroom learning experience

Using the 10 rubric criteria, indicated in Table 3, and a four-point scale, two members of the research team analysed the pre-assessment task separately, coming together afterwards to reach consensus. After the garden investigation, the same post-assessment task was administered and the same consensus process ensued. Table 3 shows the rubric criteria with the related evaluation question(s) from the assessment (see Figure 2) and learners who scored four (on the four-point scale) on the pre- and post-assessment corresponding to these criteria. Rubric items for which the post was > 40% points higher than the pre-assessment are shown in bold.

Table 3: Rubric criteria and student scores.

| Rubric criteria | Pre-assessment | Post-assessment | Change |
|---|---|---|---|
| **1. Students can accurately use a formula for area (Q1,3,4)** | **15/30, 50%** | **28/30, 93.3%** | **43.3% increase** |
| 2. Students can accurately determine perimeter (Q2) | 21/30, 70% | 28/30, 93.3% | 23.3% increase |
| **3. Students show understanding that area can be determined by decomposing a shape (Q1,3,4)** | **12/30, 40%** | **24/30, 80%** | **40% increase** |
| **4. Students clearly connect aspects of the area formula to the visual representation (Q 1,3,4)** | **12/30, 40%** | **25/30, 83.3%** | **43.3% increase** |
| 5. Students can use a strategy to find area to correctly create another shape with the same area (Q5) | 9/30, 30% | 16/30, 53.3% | 23.3% increase |
| 6. Students create arrays and the arrays are used to determine area (Q1,3,4) | 3/30, 10% | 4/30, 13.3% | 3.3% increase |
| **7. Students communicate clearly (Q1,2,3,4)** | **7/30, 23.3%** | **19/30, 63.3%** | **40% increase** |
| **8. Students communicate comprehensively (Q1,2,3,4)** | **4/30, 13.3%** | **16/30, 53.3%** | **40% increase** |
| 9. Students correctly designate units (Q1,2,3,4) | 14/30, 46.6% | 24/30, 80% | 33.4% increase |
| **10. Students correctly utilise designated units (Q1,2,3,4)** | **1/30, 3.3%** | **19/30, 63.3%** | **60% increase** |

## Mathematical focus based on evidence of student growth

The criteria in which students showed notable growth from the pre- to post-assessment data were in rubric criteria 1, 3, 4, 7, 8 and 10. We believe this data provides evidence of growth in the following areas:

1. Students understanding that area can be determined by decomposing a shape;
2. Students clearly connecting aspects of the area formula to the visual representation;
3. Students communicating clearly and comprehensively; and
4. Students correctly utilising designated units.

While all of the classroom experiences contribute to students developing knowledge, Mrs Riley highlighted specific activities—measuring an indoor garden bed, mathematics and science journal entries, and student presentations—as being particularly powerful in developing her students' mathematical thinking in the areas showing notable growth. In the following sections, each of these classroom activities is further described, including considerations of her students' thinking.

## Measuring spaces indoors and writing journal entries

Once students had been introduced to the project, conducted their own research, and engaged in background lessons with a focus on area and perimeter (see Table 2), Mrs Riley engaged the whole class in creating a replica garden bed in the classroom using masking tape, cardboard and precise measurements.

Students were asked to determine the area of a garden region by a process of partitioning the region into non-overlapping rectangles (see Figure 4), (a) finding the area of each rectangle using multiplicative or additive thinking, and (b) summing these areas to find total area. Further, students were asked to communicate their mathematical processes and reasoning. Students then discussed their reasoning and shared strategies for determining the area of each partition. Mrs Riley recalls classroom discussion focused on articulating the unit (each square paper) and making sure that students covered the entire garden area without gaps or overlaps. Students shared both additive and multiplicative thinking as they determined the final area of the garden region.

Mrs Riley often follows up this whole class activity with individual student journal entries. Science and mathematics journals can be used throughout the classroom experience for students to complete related problems, pose and answer questions, and reflect on classroom experiences. For example, following the whole class activity where students partitioned a large classroom space that replicated the outside garden bed measurements, Mrs Riley might ask students to answer the following journal prompt similar to one part of the pre- and post-assessment question (see Figure 5): "What is the area of shape C? Explain how you found your answer. Make sure and designate what unit you are using to measure the area of shape C."

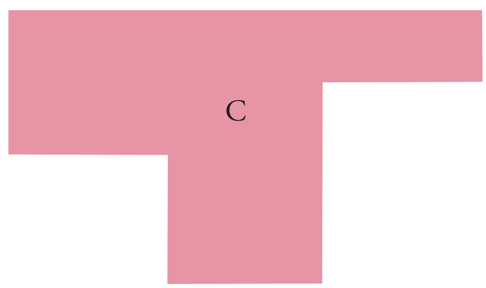
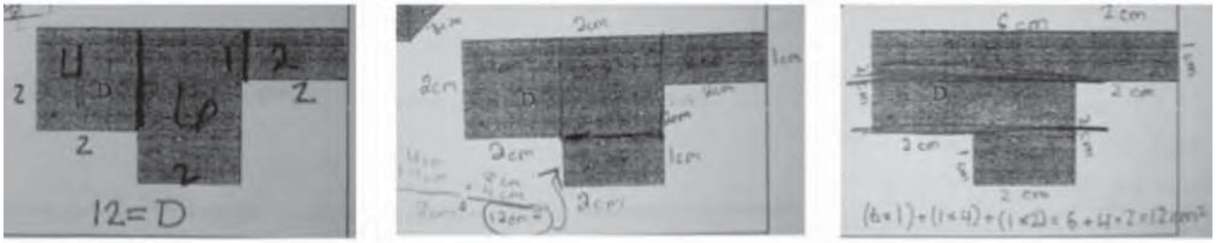



Figure 5: Rectangular region used in conjunction with the journal prompt.

Figure 4: Students using paper cut into unit squares to partition a rectangular region on floor.




(a) (b) (c)

Figure 6: Students' journal entries showing John's work (a), Cindy's work (b), and Lily's work (c).

For this journal prompt, the students were asked to designate their measurement units. Particular to students work on this task, Mrs Riley noticed the variety of ways that students partitioned similar garden regions and recognised that these different methods of partitioning offer insights into student thinking. For example, John, Cindy, and Lily (Figure 6, a – c) each correctly partitioned the rectangular regions and connected the representation to the use of multiplicative and additive thinking to determine the area of the region. These students used multiplicative thinking to determine the area of each of the rectangles and then used additive thinking to determine the area of the entire region.

Figure 6 (b) shows Cindy's work, who divided the garden into two squares (2cm × 2cm) and two rectangles (2cm × 1cm). First, she determined the area of each of the squares using multiplicative reasoning. Next, she added the area of the two squares for a total of 8cm². Then, she found the areas of the rectangular regions and added these together mentally. The last calculation shows her adding the regions of the two squares and the two rectangles for a final answer of 12cm². The other two examples (a and c) show similar thinking. However, the three examples showed differences in the partitioning methods, communication details, and precision in the use of units. For example, John's work as shown in Figure 6 (a) solely communicates that the region equals 12, thus his answer lacks a unit of measure.

Science and mathematics journal entries offer specifics in how the students' written communication on this task reflected a wide range of detail and insight into their thinking and reasoning. For example, John's work in Figure 6 (a) provided very little insight about what that work involved and showed little precision in using units (e.g., the rectangle in the middle indicates an area of 6 with no explanation of what calculations were used to determine the area). The final answer is stated as 12 = D, requiring the teacher to assume that addition of 6 + 4 + 2 led to the final answer. Cindy's work in Figure 6 (b) does not share the multiplicative calculations used to determine the area of each partitioned rectangle but does share the additive calculations used in arriving at the final answer. Finally, in Figure 6 (c), Lily very clearly communicates how the answer was found using multiplicative and additive thinking, writing the equation $(6 \times 1) + (1 \times 4) + (1 \times 2) = 6 + 4 + 2 = 12$ cm². In the latter two examples, explanations were provided concerning the units used, with the final area designated as 12 cm². Considering these differences in how students communicated their mathematical reasoning, Mrs Riley noticed that her students needed further support. She felt that she could improve students' levels of communication by asking guiding questions including, "What units did you designate and use?" or state "Please make sure to communicate those units in your responses." Further, Mrs Riley believes students have developed the ability to build an understanding of two-dimensional arrays and then to interpret two lengths as measures of the dimensions of those arrays but would like them to express this potentially abstract thinking using the rectilinear figures by asking, "I see that you found the area of each rectangle, can you show me how that number represents the area in each of the rectangles?"

## Student presentations

Students continue writing mathematics and science journal entries, experiencing mathematics lessons focused on area and perimeter, and developing an initial and final group proposal all prior to presentation day. On presentation day, each group presents their proposed garden plan. Student presentations of their proposed garden plans included several examples of how students decomposed the area of the class garden beds, which provided further opportunities for groups to communicate clearly and precisely about how they determined the area. Students then voted for the winning design, listing on a post-it note the reason for their vote. One of the wining designs illustrated in Figure 7, shows an 8-foot by 10-foot garden bed —modified to standard square units for the purposes of the design—in which students used grid paper to emphasise square units. Students declared this design the winner because they felt it had the best design for space based on plant needs, coupled with being able to easily reach different sections of the garden bed. Mrs Riley was pleased to see that the winning design was mathematically accurate while providing reasonable space for each groups' planting requirements. The larger plots were designated for groups planting yellow summer squash that require more growing space, while one of the groups had decided to grow eggplant, peppers, and bush beans, all plants requiring less space. She felt this indicated that the students were seriously considering the rationale for each option rather than just voting for their own design.

Figure 7: Students' vote for a winning design.

## Post test

Following the final presentations, and the ensuing research, development, and implementation of a final planting plan, Mrs Riley administered the post-test (see Figure 2) as a culminating assessment of students' understandings. To solve the post-assessment garden region task, most students successfully decomposed the shape into separate rectangular regions (see scores in Table 3). However, Mrs Riley notes that most students didn't create arrays and use the arrays to determine area (3.3% increase). She believes—as previously mentioned—that students have developed the ability to build an understanding of two-dimensional arrays and then to interpret two lengths as measures of the dimensions of those arrays. She plans on changing one of the questions on the pre/post assessment to explicitly ask students to demonstrate this abstract thinking using the rectilinear figures.

Interestingly, in the post-assessment three students showed intuitive methods for determining the area of a garden region, actually composed a larger region. For example, to determine the area of garden region C, Allison spatially composed a larger rectangle and then found the area by multiplying 6 × 3 (cm$^2$) as shown in Figure 8. She then decomposed the shape by subtracting the areas not part of the rectangular region (a 2cm × 2cm square and also a 2cm × 1cm rectangle).

Solutions like this student exemplar are interesting because they show that students drew on earlier learning experiences and/or intuitive methods to solve the current task at hand, thereby demonstrating students' progression along a learning trajectory for spatial reasoning (Clements & Sarama, 2009), while highlighting the on-going need to prompt students to utilise units. Perhaps Allison had experiences in previous grades such as: composing and decomposing plane figures in kindergarten (e.g., putting two congruent isosceles triangles together to make a rhombus); building an understanding of the properties of different shapes during first grade; and intentionally substituting arrangements of smaller shapes for larger shapes or substituting larger shapes for smaller shapes in the second grade (Clements & Sarama, 2009). All of these experiences might have contributed to students' geometric and spatial reasoning while also developing a foundation for understanding area.

## Actual planting considerations

After the determination of the winning garden plan, students revisited varied media resources to verify any additional information they might need based on the final design plan. As described in the introduction to this article, one can imagine the day that all of the students' hard work and planning is put into action. Mrs Riley noted that the outside garden work involved

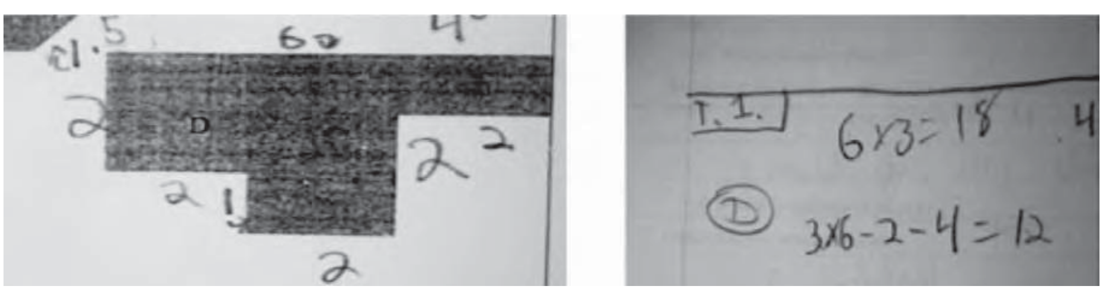



Figure 8: Allison's solution involving composing a larger rectangle around the rectangular region.

Figure 9: Image of students partitioning their garden bed with string.

obtaining and organising all of the materials (e.g., seeds, tools, soil, string to partition beds), considerations, and organisation so that the students adhered to the class plan in order to best ensure that the class garden will flourish.

Using the classroom developed garden plan, students put their plan into action as they created an outdoor garden space as shown in Figure 9 while concurrently having developed knowledge in the mathematical concepts of area measurement.

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