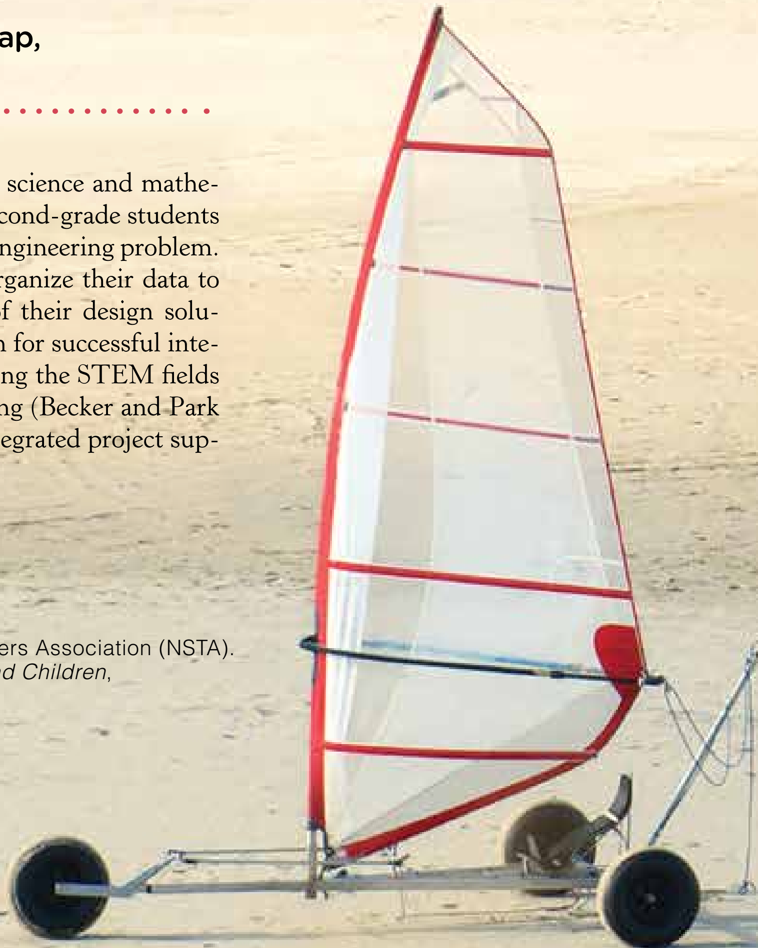
Sailing Into Integration

Planning and implementing integrated 5E learning cycles

By Laura Robertson, Eric Dunlap, Ryan Nivens, and Kelli Barnett

This 5E learning cycle integrating science and mathematics challenges and engages second-grade students in designing sail cars to solve an engineering problem. Students create and use line plots to organize their data to evaluate the strengths and weakness of their design solutions. Three strategies were used to plan for successful integration in a 5E learning cycle. Integrating the STEM fields can increase student interest and learning (Becker and Park 2011), and our experiences with this integrated project support this finding.



The integrated learning activities and assessments presented here are the result of collaboration between elementary classroom teachers, preservice teachers, and higher education faculty, but the strategies we used could be implemented by anyone seeking to integrate math and science in an elementary classroom.

Planning for Science and Math Integration

Strategy 1 – Pick the science standard first and then look for connections to math.

From our experience, it is easier to start with a science standard and then integrate math into it because the math standards are broader and have a greater number of applications. We asked elementary classroom teachers for a list of science standards that they felt would be the most difficult to teach. Most of the standards selected by the teachers were related to physical science or engineering.

Strategy 2 – If in doubt, integrate measurement and data standards.

Taking the standards given to us by the elementary teachers, we assigned one standard each to approximately 50 preservice teachers. They were tasked with identifying a math standard to integrate. Due to the nature of science as applied mathematics, we suggested the domain of measurement and data. The majority of our students were able to find a natural fit for this area of mathematics into their assigned science standard.

Strategy 3 – Find the balance between teaching and assessing the content areas together and separately.

We find that it is not necessarily desirable for math and science to be integrated during all phases of the 5Es. In this learning cycle, there are subject-specific points during the Explore and Explain phases to guide and support student learning while the Engage, Elaborate, and Evaluate phases are integrated (Table 1). We did not pre-plan this balance of integration and subject-specific learning, rather it emerged as we considered what would work best for the students and for this set of activities.

5E Learning Cycle: Sail Car Engineering

This 5E learning cycle is an adaptation of the activity "Wind-Powered Sail Cars" (Anderson 2017), with added components to address integrated math and engineering content aligned to the *Common Core State Standards* (CCSSO and NGAC 2010) and *Next Generation Science Standards* (*NGSS*; NGSS Lead States 2013). A complete materials list and estimated costs for a class of 24 students working in pairs are provided in Figure 1.

FIGURE 1

Materials list.

Consumable supplies

Car bases

- Thirty 1/8 inch dowel rods 48 inches long ($10)
- Two rolls of electrical tape ($3)
- Wood beads ($6)

Sails

- Wax paper ($2)
- Aluminum foil ($2)
- Cloth – 1 yard ($2)
- Sandwich bags ($2)
- Paper towels ($1)
- Optional (copy paper and/or cardstock)

Other

- Sticky notes ($2)

Total of consumable materials: $30

Nonconsumable supplies

- Box fan (6 to 9 inch) $10 to $15
- Powerstrip or foot switch ($7)
- (2) cloth measuring tape (150 cm or longer) ($3)

Initial setup cost with all materials: $50

Engage: Day 1 (15 Minutes)

To engage students in the lesson, we showed a short video of a land sailing competition (see Resources). After the video, students were asked discussion questions such as "How do you think these sail cars work?" "How far do you think the sail cars traveled?" "How would the distance traveled be measured?" and "Did all of the sail cars look alike? How were they different?" The questions prompted higher-order thinking, and the students engaged in a lively discussion and exchange of ideas. For example, one student stated: "They had different shapes, sizes, and colors" while another student noted, "The shape was different at the bottom where the person was sitting." We then introduced the problem statement of the unit: "Use a set of provided materials to design a sail car that travels the longest distance possible."

Explore: Day 1 (45 Minutes)

After the video and discussion, we began the first hands-on activity in which students designed and tested sail cars. We moved students to the cafeteria for the Explore phase, because that was the best location to set up the test areas. The teacher grouped students in pairs based on who students were in conversation with during the Engage phase and with consideration of which students worked well together. Each pair of students had a kit of assorted materials with which to build the sail including pre-cut dowel rods, fabric, wax paper, card stock, and aluminum. The bases for the sail cars were premade to save time and because assembly of the bases requires more fine-motor skill than the sails. To assemble the bases, we used five dowel rods that were five inches long. Four rods were used to make a square with the fifth rod bisecting the square. We threaded two wooden beads on front and back dowel rods (four beads total) to act as wheels. The base was held together using electrical tape, and a piece of electrical tape was placed in the middle of the front and back rods to keep the wheels separate.

As a safety precaution, students were instructed to be careful with the dowel rods (because the ends of some of the dowel rods were rough) and to not put the beads in their mouths. Students wore goggles during construction and testing. Students designed the size and shape of the sails for their cars as well as how to attach the sail to the base. Construction of the sails was completed by the students with minimal support from an adult. Students made drawings of their sail car designs on a provided handout that served as a formative assessment. The drawings were completed after construction as a record of their designs. As teachers, we were looking for student drawings to accurately represent the shape and materials used to create the sail.

TABLE 1

Balance of integrated and subject-specific learning.

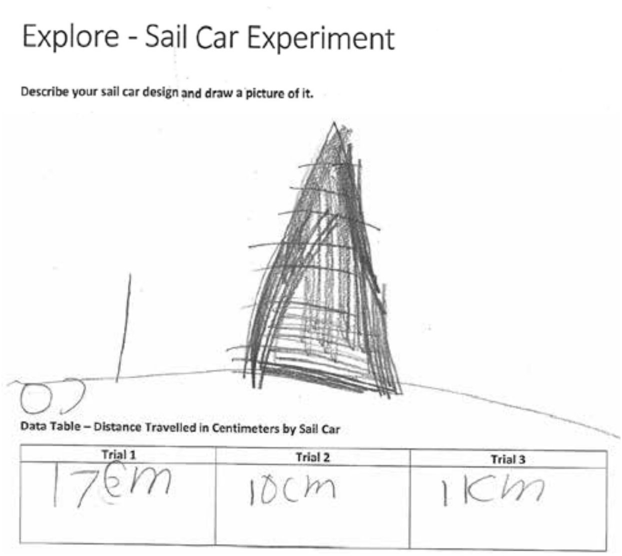
5E PHASE	INTEGRATED LEARNING	SUBJECT-SPECIFIC LEARNING
Engage	Ask questions to prompt prior knowledge and address math and science.	
Explore	Students design solutions to the problem statement and use measurement to collect data.	Math: The teacher reviews basic strategies, such as reading a tape measure to the nearest whole unit and measuring to the front or back of the car.
Explain		Math: The teacher leads a discussion about the basic layout of a line plot and how it helps organize data. Science: The teacher leads a discussion of multiple solutions to a design problem and evaluates strengths and weaknesses of a design solution.
Elaborate	Students redesign and test sail cars and create line plots of their data to use as evidence.	
Evaluate	Students write a CER summary of the activity in which math and science content are integrated. Assessment of science and math is also integrated.	

Math focus. After students constructed their sail cars, we reviewed the math measurement skills needed to accurately measure the distance travelled by the cars. We found that metric units of measure, in particular centimeters, would provide an accurate measurement. The metric measuring tapes we used provided a continuous series of numbering without introducing additional units (i.e., inches are usually interrupted by markings for feet).

For testing, we set up two areas with a fan and a pre-marked "track" of 300 cm made by taping a measuring tape to the floor. The fans were set on the lowest speed and as a safety precaution were turned on and off by an adult using a surge protector. Once a student placed a sail car on the starting line, the fan was turned on and students observed the motion of their sail cars. Students completed three trials for their cars and measured and recorded the distance travelled to the closest whole unit (cm) (Figure 2). Students wrote the distance travelled on a blue sticky note and placed it on a number line on the wall. After testing, we moved the line plot from the cafeteria to the classroom to use in the discussion on the following day.

FIGURE 2

Example data table.


Explore - Sail Car Experiment

Describe your sail car design and draw a picture of it.

Data Table – Distance Travelled in Centimeters by Sail Car

Trial 1	Trial 2	Trial 3
17cm	10cm	1Km

FIGURE 3

Sticky notes placed on the line plot allow students to see the differences in the data.

Explain: Day 2 (20 Minutes)

Math focus. During a whole-group discussion, students summarized the data represented on the class line plot and brainstormed names for the representation. When summarizing the data, we asked the students questions such as "How far did most of the sail cars travel?" and "What are the greatest and shortest distances recorded?" We intentionally did not use the term *line plot* with students prior to this. Students generated name ideas such as *number plot*, *number house*, and *line plot*. We shared with students that the term *line plot* had been selected by a previous group of scientists and mathematicians who came together and discussed the best name for it. After the line plot for the group was recorded by the class of students, we discussed its size and asked students what would be necessary if each of them was going to create the line plot in their notebooks. Students suggested shrinking the line plot down in order for it to fit in their notebooks.

Science focus. The purpose of the science portion of the Explain phase was to discuss the results of the Explore activity in the context of the problem statement. We asked the students whose sail cars had traveled the farthest to set their sail cars in front of the line plot at the distance traveled. Then as a group, we discussed what these cars had in common and how they differed from other designs. To compare and contrast solutions, we introduced the concepts of strengths and weaknesses of design solutions. From this discussion, students noted that the designs that traveled the greatest distances used paper or aluminum foil for the sail. The sails were oriented to "catch" the wind, were supported with one or more sticks (masts), and did not have excessive amounts of tape. In conclusion, students talked with their partners and planned the redesign of their sail cars.

Elaborate: Day 3 (30 Minutes)

Students were excited to redesign and retest their sail cars. We provided students with access to the same materials from the Explore phase and 15 minutes of build time, and we reiterated the safety precautions. Student discussions during the redesign process included phrases like, "it needs to catch the wind like a parachute," "we have too much tape here," and "there are too many holes in the paper towel compared to the aluminum foil." Students also simulated testing during their redesign by blowing on the sails and testing to see if the wheels could turn freely. Students used a second handout (and formative assessment) to draw their redesigned sail cars and record data in a table for their results for each trial. We used pink sticky notes on the line plot for the second day of testing so students could easily see the differences in data from the two days (Figure 3).

After we finished testing, we had a group discussion of the data from the Explore and Elaborate phases. Students examined the line plot showing color-coded data and summarized it. For example, one student stated, "Yesterday there were

FIGURE 4

CER student prompts and target responses.

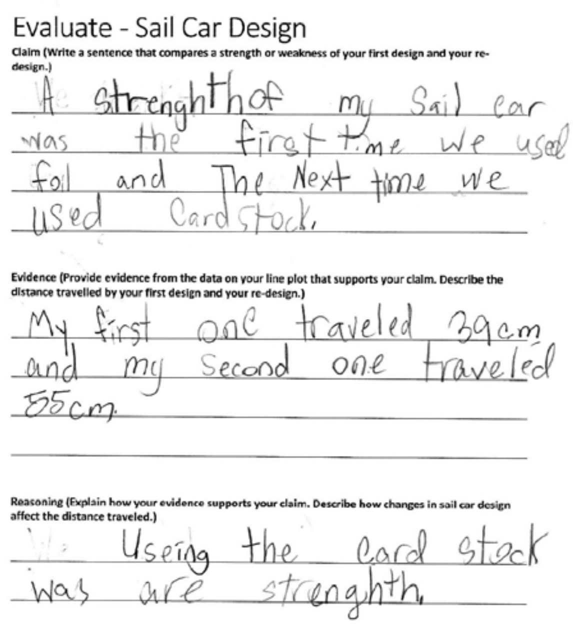
Claim (Write a sentence that compares a strength or weakness of your first design and your redesign.)
Target response: A strength of the redesign compared to the first design was using cloth to make the sail instead of cardboard.

Evidence (Provide evidence from the data on your line plot that supports your claim. Describe the distance travelled by your first design and your redesign.)
Target response: When we used cardboard for the sail, the car traveled 120 cm. When we changed the sail material to cloth, the car traveled 150 cm.

Reasoning (Explain how your evidence supports your claim. Describe how changes in sail car design affect the distance traveled.)
Target response: Changing the sail material from cardboard to cloth was a strength of the sail car redesign. The redesigned car traveled farther than the first design.

FIGURE 5

Sample student response.


Evaluate - Sail Car Design

Claim (Write a sentence that compares a strength or weakness of your first design and your re-design.)

A strenghth of my Sail car was the first time we used foil and The Next time we used Card Stock.

Evidence (Provide evidence from the data on your line plot that supports your claim. Describe the distance travelled by your first design and your re-design.)

My first one traveled 39cm and my Second one traveled 55cm.

Reasoning (Explain how your evidence supports your claim. Describe how changes in sail car design affect the distance traveled.)

Useing the Card stack was are strenghth.

Sample student sail car.

lots of zeros, and today there are not." Another student said, "The farthest one from yesterday was only 131 cm and today was 258 cm." Students then created a line plot for their science notebooks representing data from the Explore and Elaborate phases for their sail car. Small stickers in blue and red were used to mark distances traveled by the two designs. Even though there was variation in the data for trials, patterns for the designs were still evident. When discussing the data, we would hold up a line plot in a student's notebook and ask students to interpret it. Students were able to accurately summarize the relevant patterns in their own data and the data of their peers. Students' individual line plots were used as a third formative assessment to determine if students could accurately graph their data on a number line.

Evaluate: Day 3 (30 Minutes)

Students used their data from the Explore and Elaborate phases to complete a Claim, Evidence, and Reasoning (CER) response. We created student prompts and target responses in advance to help us guide students through the process as a group (Figure 4, p. 65) and to gauge student responses.

Students were encouraged to describe aspects of their designs and support their arguments with evidence from the line plot. We made the following sentence stems available to students to support the formation of their comparisons, but use of the sentence stems was not required:

- "The (greatest/shortest) distance traveled was ____cm, and this design had __________ (insert description of sail car)."
- "Designs that included __________ (insert description of sail car) usually travelled (longer/shorter) distances than other designs."
- "Based on the data, __________ (insert description of sail car) is a (strength/weakness) in sail car design."

Student responses were completed individually and reflected their designs and data (Figure 5, p. 65). The CERs were the summative assessment of the 5E learning cycle, and they were evaluated using a rubric adapted from Zembal-Saul, McNeill, and Hershberger (2013; see NSTA Connection).

Conclusion

The students found this integrated 5E learning cycle extremely motivating. They were very focused and enthusiastic during the project and throughout the day; we overheard many conversations about what could be changed or adjusted to the sail cars for the redesign. In ways that were planned and unplanned, the integration of science and mathematics contributed to a deeper understanding of the content and practices of each discipline. Students were doing the work of engineers and using mathematics as a tool to solve real-world problems—an experience that was not lost on the students. The class had recently read the book *Rosie Revere, Engineer* (Beaty and Roberts 2013), and one student confided to the teacher, "I think we might be acting out that book." ●

INTERNET RESOURCES

Anderson, E. 2017. Wind-powered sail cars – activity. Retrieved from *www.teachengineering.org/activities/view/ucd_sailcars_activity1*

Eisenlohr, J. 2014. Landsailing world championship [Video File]. Retrieved from *www.youtube.com/watch?time_continue=1&v=tKqoYj_LoHU*

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Beaty, A., and D. Roberts. 2013. *Rosie Revere, engineer*. New York: Abrams Books for Young Readers.

Becker, K., and K. Park. 2011. Effects of integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: A preliminary meta-analysis. *Journal of STEM Education: Innovations & Research* 12 (5/6): 23–37.

National Governors Association Center for Best Practices. 2010. *Common Core State Standards Math*. Washington, DC: National Governors Association Center for Best Practices.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states*. Washington, DC: National Academies Press.

Zembal-Saul, C., K.L. McNeill, and K. Hershberger. 2013. *What's your evidence?: Engaging K–5 students in constructing explanations in science*. New York: Pearson Higher Ed.

Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

Standard

K-2-ETS1 Engineering Design

www.nextgenscience.org/dci-arrangement/k-2-ets1-engineering-design

- The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities.
- The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectation listed below.

Performance Expectation

K-2-ETS1-3. Analyze data from tests of two objects designed to solve the same problem to compare the strengths and weaknesses of how each performs.

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practice	
Analyzing and Interpreting Data	Students measured distances traveled by sail car designs to the nearest whole unit (cm), created a line plot of measurement data to show distances traveled by sail car, and compared data from line plots to determine optimal design plan.
Disciplinary Core Ideas	
ETS1.C Optimizing the Design Solution Because there is always more than one possible solution to a problem, it is useful to compare and test designs. **PS1.A Structure and Properties of Matter** Different properties are suited to different purposes.	Students compared strengths and weaknesses of sail car designs. Based on test results, students redesigned sail cars. Students compared strengths and weaknesses of property designs of the sail cars. Students used property comparisons and line plot results to influence their redesigned sail cars.
Crosscutting Concept	
Structure and Function	Students connected sail car performance to strengths and weaknesses of design through claims, evidence, and reasoning.

Connecting to the *Common Core State Standards* (NGAC and CCSSO 2010)

Mathematics	
2.MD.D.9	Generate measurement data by measuring lengths of several objects to the nearest whole unit, or by making repeated measurements of the same object. Show the measurements by making a line plot, where the horizontal scale is marked off in whole-number units.
2.MD.A.1	Measure the length of an object by selecting and using appropriate tools such as rulers, yardsticks, metersticks, and measuring tapes.

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