A System of Systems

A STEM investigation project for intermediate students has real-life connections

By Barney Peterson

System: A group of interacting, interrelated, or interdependent elements forming a complex whole, or a functionally related group of elements.

"Hey, Mrs. P, what's that thing for?" "How come the ceiling looks like that?" "Why are there handles on those pipes in the hallway?" "How does that thing work?"

The first months in our new school were punctuated by dozens of student questions: in the hallways, in the classrooms, in the cafeteria—everywhere we went. Our new school, besides being built to be environmentally friendly, is designed in a fascinating industrial-tech style that uses non-traditional finishes and exposes many of the normally hidden parts of a building to view. Because my students were so intrigued by things they noticed, the construction manager and I decided to capitalize on their curiosity and create an authentic learning opportunity that supports the growing emphasis on STEM education. Our goals for this unit were to help the students understand Systems and System Models in real-world contexts: to be able to distinguish the parts of systems and their functions. This relates to *NGSS* Crosscutting Concept System and System Models (NGSS Lead States 2013).They would also use the speaking, listening, technology, and teamwork skills we had developed to create a communications product for an audience beyond our classroom.

Learning to Use the Tools

While our main project was still in the planning and development stage, I enlisted our school learning resource specialist (LRS) to help students gain experience writing scripts and choosing visuals to share specific information (CC ELA Connection: Speaking and Listening #5: Make strategic use of digital media and visual displays of data to express information and enhance understanding of presentations). Students were taught how to develop video presentations using two different platforms available at our school: PCs and iPads. Students worked with the LRS during weekly library periods and used daily literacy block time in the classroom to complete these projects. This experience would provide the skills and practice necessary for them to communicate what they learned in the project with a broader audience beyond the classroom.

Figuring Out the Systems

The students and I decided to take a systems approach to organizing our research. We were already familiar with the idea of systems from our yearlong units raising salmon in our classroom and studying watershed ecology to understand salmon habitats. Students had learned about body systems in salmon anatomy and how they support the survival of the whole animal. They had also studied watershed ecology from the viewpoint of river and stream systems, so they had a basic idea of how to search for and recognize the parts of a system. This provided an opportunity to extend our understanding of systems to include physical science as well as life and Earth science. We posted "System: A group of interacting, interrelated, or interdependent elements forming a complex whole, or a functionally related group of elements" to guide us as we investigated what systems were present in our new school (*NGSS* Crosscutting Concepts Systems and System Models: a system can be described in terms of its components and their interactions [NGSS Lead States 2013, p. 38.])

While the class discussed all the parts and functions we could think of that are normally required to make a building run, I created a list of their ideas on the whiteboard. As a group, the class walked around our school, enthusiastically discussing what we saw and taking pictures of everything that caught our eyes or piqued our curiosity. Students worked in teams of four, each team with one iPad. They captured pictures of switches, pipes, wires, holes, covers, color patterns, material surfaces, and more. Back in the classroom, student teams gathered noisily around tables to examine their photos and delete duplicates, then I printed out paper copies so teams could sort and organize them into related sets like lighting, decoration, wiring, walls, and floors, based upon what function we thought each might serve. Because our school was described by district officials as being "green," a team of three students researched "green construction" to help us understand that label. It was time to call in the experts!

PHOTOS COURTESY OF THE AUTHOR

Students examine building plans.

Learning From the Experts

I enlisted the help of Darcy Walker, a district construction manager who was involved in building our school. Together we planned how to organize this project. He worked with the class to narrow our ideas to a list of seven major systems: Civil, Data and Communication, Electrical and Lighting, Fire and Safety, HVAC (Heating, Ventilation and Air Circulation), Landscape and Design, and Structural. From there, Mr. Walker and I sought speakers who could help the students understand the parts of each system and how they work, separately and together. He enlisted seven people involved in the design and construction of our building and scheduled their visits. They included both males and females from design and engineering fields to provide students with exposure to diverse career opportunities and to show them that accessibility to those careers is not limited by gender or ethnicity.

Earlier in the school year there had been guest speakers from the public utilities for water, gas, and electricity who visited our class to help students learn about the importance of using sound construction methods and materials for efficiency and economy. They engaged students in hands-on experiences such as investigating how air flows through rooms, affecting heating, and the amount of energy used by various kinds of lightbulbs. Our new series of speakers built upon students' understanding from those earlier experiences to help us discover environmentally friendly features of the building (3-5-ETS1 Engineering Design; Crosscutting Concept Influence of Engineering, Technology, and Science on Society and the Natural World). These included saving energy by use of LED lighting, maximizing natural light with large classroom and clearstory windows, choosing a site drainage system with built-in filtration for surface water runoff, and developing ways of recovering heat from the heat recovery system to use in other ways in the building.

Speakers came equipped with samples of materials, construction drawings, and slide shows to help students understand special features of the new building. As exhibits were passed around and handled, students asked questions and responded to prompts from speakers to learn how the materials worked. Asking about levers on the big silver pipes overhead lead to discovering how dampers in the ductwork control the airflow through the ventilation system to constantly integrate fresh air from outside with heated air and provide a healthier atmosphere. When a student pointed out the silver "buttons" on classroom ceilings, we all learned about how the fire suppression sprinkler system is disguised with pop-off covers. While touching pieces of "rebar," students discovered that the "bumps" on the bar actually help to hold it solidly in place in the concrete foundations and walls of the building. Students expanded their understanding of "reduce, reuse, and recycle" to include energy as well as materials when they learned that, as our old school was demolished, it was actually carefully dismantled and materials were separated for recycling. The mechanical engineer showed how a particular device is used to recover heat from air that has already circulated through the school before it is pushed outside: this heat is used to help warm fresh air as it enters the system. A rewarding "aha!" moment happened when a student said to me "Hey, that's like the radiator on our car, right?"

All of the speakers had prior experience working with students in a variety of formal and informal situations and needed very little coaching to prepare them for working with us. We encouraged them to bring visuals and hands-on examples whenever possible to tap into the variety of learning styles the students use.

A System of Systems

Meanwhile, students began re-sorting photos into the systems and posting them on our "A System of Systems" wall. This visual organizer was continually modified as our understanding of the systems and their subsystems grew (Figure 1, p. 78). Students began to question which systems were entirely separate and how the systems depended upon each other to work. We discovered components that supported each other and were organized into systems that accomplish particular critical functions in the building. Students prepared for our speakers by discussing what we already knew about the systems and things we had observed during the building of the new school: the ground-shaping and forms built for footings and walls; trenches and plastic pipes through which wires ran; more metal, concrete, and bricks than wood used in walls; huge wooden beams in the roofs. Students recorded and discussed their questions as they sorted photos and listened to speakers. After the last of the individual system component videos were finished, a team of three students took on the task of organizing and explaining this in an overview video segment (see NSTA Connection).

Since the new school was built within feet of our old facility, there were daily opportunities to observe the deconstruction and materials salvage of the old building as well as the ground-up building of the new school. The old school consisted of six hexagonal pods of classrooms and three semi-rectangular support units. Instead of hallways, there were covered walkways between buildings. Our architect used photos and drawings to help students work through how he designed a new, larger school to replace the old school on the same amount of property. We saw that the new school used the same area-footprint as the nine old buildings and walkways. By adding a second story, we had a larger school and still had room for playgrounds, athletic field, and parking lots on the same property. The two-story building also made more effective use of a single HVAC system. Later, the civil and structural engineers demonstrated how two-story construction required different materials and techniques to create a strong, safe, energy-efficient building. We used construction drawings to compare the new school to the old school. We learned to look at drawings and see three-dimensional figures as students discovered how math and reasoning skills are used in models to address the challenges involved in planning and building. For example, the way special foundations in the ground were required to support the weight of a large brick wall that stands alone as part of the roof design particularly intrigued the students. This helped them learn about supporting greater weights with a large base to ensure stability and how the architect and structural engineers cooperated to design a workable system that complemented the overall design of the building. Students continued to refer back to the construction drawings throughout the nine months of this project. This helped them understand the spatial relationships between parts of systems and the working connections that kept all systems functioning. An example would be looking at wiring diagrams to see that the electrical system connected to almost everything else in the building.

Calling on Community Resources

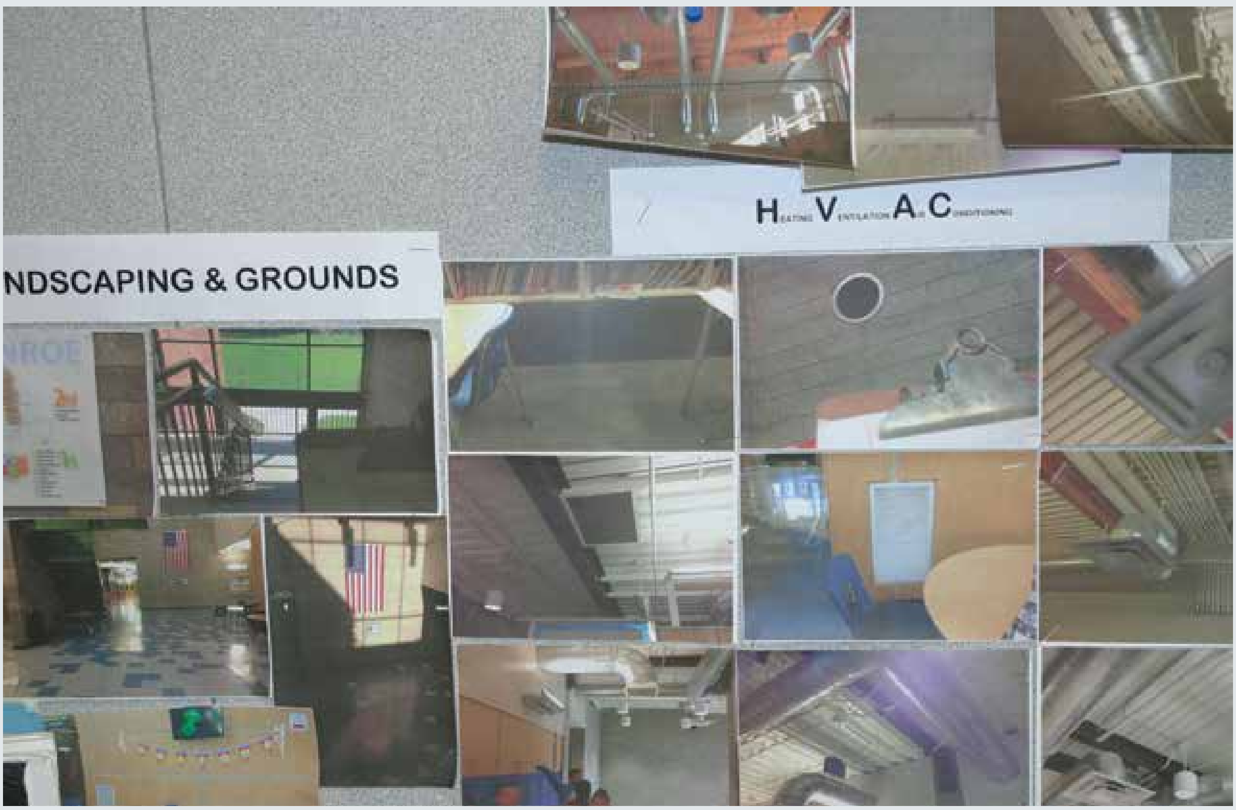
Our first visitor was the lead architect for the project. He began with a wonderful analogy describing the work of planning and building a school as teamwork organized much like our local NFL team with a manager, coaches, and players who specialized in certain roles, but all of whom work together to win games. Before he ever got into the details of design, he helped the students gain new understandings of systems, both as the building and its parts and as the working groups of people who create it.

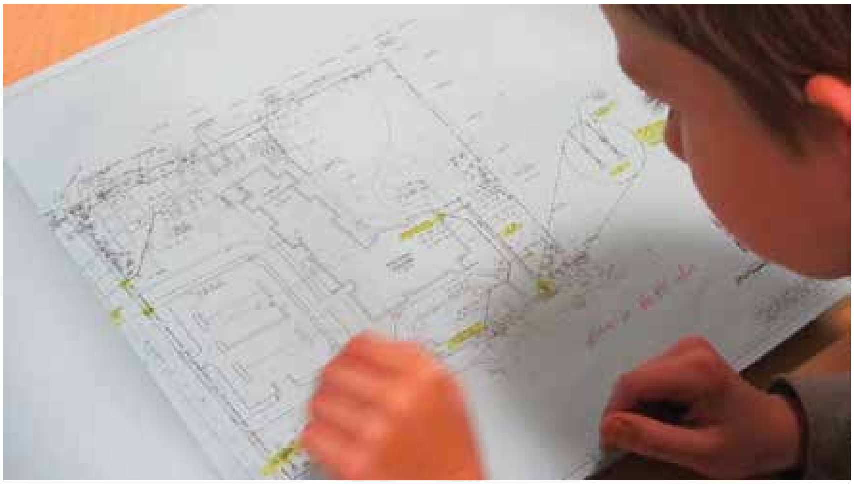
Speakers came two or three days apart: electrical, civil, structural, mechanical, safety, and design were all presented by professionals specific to each field, exposing the students to the science of building design and construction. As they listened to our speakers, students took notes and asked questions to grow their understanding of how so many parts are organized and coordinated into one huge functioning system. During his presentation, the structural engineer made a deliberate point of engaging the students in dialogue to discover how much they knew about the earthquake-prone area in which we live. He had prepared a special PowerPoint presentation to help the students understand how living in an earthquake-prone area requires buildings to be stronger and more flexible (see NSTA Connection). That, combined with a demonstration using a shaker table, helped students realize the teamwork between geoscientists and civil, structural, and geotechnical engineers that goes into making our public buildings safe. This relates to *NGSS* Disciplinary Core Ideas ESS3.B: Natural Hazards and ETS1.A: Defining and Delimiting Engineering Problems (NGSS Lead States 2013).

Speakers also engaged students in conversations about career opportunities and the educational preparation required for taking advantage of those opportunities. This proved to be one of the surprise rewards of the project as individual students began to pursue information about specific careers that interested them. I encouraged

FIGURE 1.

A section of the System of Systems organizer wall.





All students had an opportunity to return to drawings and original notes to verify the material they included in their narratives.

students to extend their relationship with our speakers, using them as a resource for additional information.

Sharing Our Information

After the speakers, it was time for students to reorganize and refine their information, linking it with specific images, and then writing scripts for the videos they would create to explain our building and its systems to others. Students were assigned in groups of 3 or 4 with a mix of ability levels, genders, and language proficiencies. Students in this class often work in groups of this nature to support each other through joint research, peer editing, and English language acquisition. This communications phase was very labor intensive.

Mr. Walker took all students in small groups on behind-the-scenes tours of the school to explore areas not normally visible to the public. Because the active construction phase was finished and safety procedures were followed (such as staying in approved observation zones), additional safety equipment like hardhats or safety glasses was not required. During the tours students took photos and asked questions. The tours proved to be a valuable tactic, especially in expanding their knowledge of how buildings are designed with backup equipment against possible emergencies or failures.

Mr. Walker also took on the task of writing brief background narratives in plain talk, linking systems and subsystems together to help students organize their presentations. He and I then sat down with each system-team and discussed how they could write their scripts to ensure only accurate, important information was included. We concentrated on asking questions to reveal their understanding and any areas where they needed more clarification to report accurately. A priority for the project was having students share learning in their own language and style. Where necessary, we facilitated students finding or correcting information. This sometimes meant an extra visit to specific areas such as the boiler room or the elevator control room to clarify ideas about how things really work. Next, each team presented a draft script to other teams for peer review, focusing on clarity of information for communication with an audience that would know very little about how a building functions.

Once scripts were developed, teams found quiet spots to practice recording and playback for fluency and timing. They critiqued and perfected their audio together prior to recording the videos. Once live tracks and still photos were aligned with audio, finished videos were created and then uploaded to School Tube where they were assigned URLs which could be linked to QR tags (see Internet Resource). We learned how to use the "Tag Maker" program to create a specific code for each video. The next step was to print the QR tags and post them in the school. This allows anyone in the school to use a Smartphone or tablet computer with a code-reader app to scan the QR tags and play the videos to learn about our school as a "system of systems." The district facilities and planning department funded manufacture of high quality, durable signs, to ensure that they would match school design.

Evaluation

Before any signs were posted, students had one final important step to complete. We had planned for evaluation right from the start of the project with students helping to establish the goals and criteria by which they would be evaluated at the end of the project. As a first step, we employed a two-color response form that students and I developed from the project plan: Each student used a yellow highlighter to color in boxes rating themselves on specific criteria and then I used a blue highlighter to record my ratings. I met with students individually to discuss our ratings. When we agreed that student work was satisfactory (boxes showing green) work was considered accepted. In areas where blue and yellow showed separately, we would discuss differences and plan how to resolve them. All areas were required to earn green coding before final videos were uploaded to get URLs, and QR tags were made to put on signs.

Formal evaluation was developed to expand on the simple two-color response form. Where the response form was designed for approval prior to posting the teams' products, this formal rubric provided a tool for grading (see NSTA Connection) (*NGSS* Performance Expectation 5-ESS3-1 Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment).

Each student was evaluated on engagement and participation as a team member and their personal contributions to the process. Each student had opportunities to demonstrate reaching objectives: recognizing systems as they were encountered and understanding the interdependency of their parts, conducting research using a variety of information resources; writing scripts; communicating verbally and in writing; and effectively using communications technology.

After videos were recorded, URLs were assigned and QR tags were created. We exposed our product to a test audience of students, teachers, and district employees. We evaluated feedback about how well the tour worked: Was it well organized? Were individual components and systems explained clearly? Were there areas we missed or important points we neglected? Did the tags work correctly to activate the videos? Were recordings clear? Did the audience understand the purpose of demonstrating how our school works as a "system of systems?" Some adjustments were made in response to feedback we received.

Reflection: It's the Journey...

Throughout this project, students were encouraged to use their curiosity about unfamiliar things to extend their learning. They raised important questions, worked effectively in teams and with outside experts, and improved their communications skills. By engaging the students with Mr. Walker and speakers from the building team, we provided opportunities to learn about careers and the importance of post–high school education early in students' school experience. Commitment of time and resources by the facilities and planning department demonstrated how interdepartmental teamwork can provide powerful support for student learning. Because our students learned about how our school was designed and built and how it is supposed to function, they acquired a valuable sense of investment in our building. Producing the building tour to share with others was a big achievement for the students, but in the long run the greatest value and pleasure from this project came from the investigation phase that actively engaged students with experts, ideas, and resources that were totally new to them.

Learning Results and Future Considerations

Students from the fourth-grade class who started this project were unable to complete it by the end of their fourth-grade school year, so 15 of the 24 original class members were recruited as fifth graders to reassemble in my classroom after school one day each week for three more months during the next school year to finish up their videos. In conclusion, they were given the opportunity to meet with me and Mr. Walker to reflect on the project. We included two of their current fifth-grade teachers who were new to our school. Students proudly gathered around an electrical and data systems closet and amazed their teachers with the depth and breadth of their knowledge about the identity and function of the sea of multicolored cables and connectors. In a round-robin conversation, they revealed what they had learned about how information is relayed through fiber optic cables and moved on to explain how the invisible-beam smoke detection system works. They had just begun to talk about the HVAC system when it was time for them to go home. The information they had retained and the depth of the questions they asked and answered was testimony to the effectiveness of this hands-on, active learning experience.

Our System of Systems project was not, according to the students, finished when the 21 short videos were completed and their signs were posted. A team of three fifth graders came back to my classroom twice each week for an additional two months in the spring of 2014 to create one more piece of the project: a longer video that examines all the systems and identifies one system that unifies them. This last video demonstrated just how much they had grown in their understanding of systems. They brought their project to a satisfying conclusion when they presented the video at the District's STEM fair at the end of the school year (see Internet Resource).

For others considering a similar project, I would suggest having a very clear purpose from the start. Make sure students recognize that they will be communicating with both adults and children so they need to learn as much as possible about their topic before they try to share what they have learned. In a project this huge and so far outside the comfort zone of many children this age, working in small teams is critical. That will help ensure teamwork and teacher time are spread more evenly and visibly. Making use of outside speakers gave the research and instruction a special feeling that called for students to pay attention and learn as opportunities were presented. It is also critical to be very flexible and not set short deadlines on a project of this nature. ■

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

3-5-ETS1 Engineering and Design

www.nextgenscience.org/5ess1-earth-place-universe

The materials/lessons/activities outlined in this article are just one step toward reaching the Performance Expectations listed below. Additional supporting materials/lessons/activities will be required.

Performance Expectation

3-5-ETS1-1. define a simple design problem reflecting a need or want that includes specified criteria for success and constraints on materials, time, or cost.

Science and Engineering Practice

Asking Questions and Defining Problems

Disciplinary Core Ideas

ETS1.B: Defining and Delimiting Engineering Problems

- The success of a design solution is determined by considering the desired features of a solution.

ESS3.B: Natural Hazards

- A variety of hazards result from natural causes. Humans cannot eliminate the hazards but can take steps to reduce their impacts.

Crosscutting Concept

Influence of Engineering, Technology, and Science on Society and the Natural World

Systems and System Models

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

CCSS.ELA-Literacy-SL.4.5

Add audio recordings and visual displays to presentations when appropriate to enhance the development of main ideas or themes.

Barney Peterson* (bpeterson@everettsd.org) *is a fourth-grade teacher at Monroe Elementary School in Everett, Washington. Darcy Walker is a construction manager in the facilities department of Everett Public Schools.

References

National Governors Association Center for Best Practices and Council of Chief State School Officers (NGAC and CCSSO). 2010. *Common core state standards.* Washington, DC: NGAC and CCSSO.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states.* Washington, DC: National Academies Press. *www.nextgenscience.org/next-generation-science-standards.*

Internet Resource

"A System of Systems Overview" video *www.schooltube.com/video/6907880ef74d463393fd*

NSTA Connection

For a sample cooperative grading sheet, the systems template, and the formal rubric, visit *www.nsta.org/sc1501*.