Nature- Inspired Design: A PictureSTEM Curriculum for Elementary STEM Learning

Tamara J. Moore
Purdue University
INSPIRE!: Institute for P-12 Engineering Research and Learning

Kristina M. Tank
University of Minnesota
STEM Education Center

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Abstract

As we look to the future prosperity of our country, there is a rising need to be better preparing our students for the complex and multidisciplinary problems that they will face in the future, and we can help to address this need by improving students' learning, motivation and experiences in STEM. In order to motivate more students to pursue careers in STEM fields, children's exposure to engineering should begin at the elementary level. However, as state and national documents call for engineering to be integrated into science instruction there is a need for more lessons that facilitate this integration. However, time and resources are one of the many challenges for doing this meaningfully. Furthermore, when looking at the current structure of STEM learning in K-12 classrooms, these disciplines are often taught in a siloed manner as single subjects instead of in the multidisciplinary manner in which they are often used in the real-world. This suggests the need for new models of STEM learning that highlight the interconnectedness of STEM disciplines by attending to the specific content as well as the overarching ideas.

The purpose of this paper is to describe the PictureSTEM project and the development of curricular units for each of the grades K-5, which integrate STEM and literacy content instruction in meaningful and significant ways. Each curricular unit consists of 5 to 10 lessons that use very little consumable materials and engage students with concrete materials that are typically already available in the elementary classroom. These units have been developed through a design-based research study based on the Clements (2007) curriculum development framework. This paper will focus on the fifth grade unit, which addresses animal and plant adaptations through an engineering design project focused on biomimicry or design inspired by nature.

Introduction

There has been an increasing need for engineering education in elementary classrooms in order to meet the complex and multidisciplinary problems that face our society. Additionally, integration has been suggested as a way to address the challenges of diminishing instructional time while providing students with the opportunity for engaging in realistic and multidisciplinary contexts that reflect real world problems. With many states adopting the Next Generation Science Standards (NGSS Lead States, 2013), curricula for integrating engineering and science are needed. While some models of curricula exist for this level (e.g., Engineering is Elementary), curricula that focus on explicit integration and are less expensive to buy and implement are needed.

The PictureSTEM units were developed to meet this need for explicit STEM integration modules that meaningfully teach each of the STEM disciplines. The theoretical framework guiding the development of the PictureSTEM modules was the STEM Integration research paradigm, which is defined by the merging of the disciplines of science, technology, engineering, and mathematics in order to: (1) deepen student understanding of STEM disciplines by contextualizing concepts, (2) broaden student understanding of STEM disciplines through exposure to socially and culturally relevant STEM contexts, and (3) increase student interest in STEM disciplines to expand their pathways for students to entering STEM fields (Roehrig, Moore, Wang, & Park, 2012). Additionally, the units were built from the *Framework for Quality STEM Integration Curriculum,* with each unit intentionally including a motivating and engaging context, meaningful mathematics and science content, student-centered pedagogies, an engineering design task, teamwork and communication skills (Moore, Stohlmann, Wang, Tank, Glancy, & Roehrig, in press). Each of the units includes science and mathematics picture books, STEM activities and an engineering design challenge to integrate STEM learning. This provides students with contextual activities that engage learners in specific STEM content as well as integrate concepts across traditional disciplinary boundaries**.** The engineering and literacy contexts are important features within these STEM integration units that facilitate the authentic and meaningful integration of multiple STEM disciplines**.**

Engineering as a Vehicle for Integration

The focus on engineering allows for a context in which students can explore the interdisciplinary nature of learning science and mathematics through engineering and within a real-world context (Brophy, Klein, Portsmore, & Rogers, 2008). The engineering component of these modules helps to tie the science, technology, and mathematics learning together by building off the natural interconnectedness of engineering and by requiring students to apply those concepts through an engineering design challenge**.** The recommendations for K-12 engineering education from the 2009 NRC report were used as the basis for the engineering component and suggests that K-12 engineering should emphasize engineering design, developmentally appropriate math, science, and technology skills and promote engineering habits of mind (NRC, 2009). The engineering design challenge is designed so that it highlights the understanding that engineering design is "(1) highly iterative; (2) open to the idea that a problem may have many possible solutions; (3) a meaningful context for learning scientific, mathematical, and technological concepts; and (4) a stimulus to systems thinking, modeling, and analysis" (NRC, 2009, p.4).

Using Literacy to Support STEM Learning
The literacy component builds upon the idea of integrating across multiple disciplines by using high-quality science and mathematics trade books to enhance and extend the instruction. These books provide students with background knowledge and a context that also helps to facilitate the STEM learning within these units**.** These units use of trade books to provide up-to-date content that is more engaging, relevant, and accessible to students due to the excellent visual features and high-quality writing when compared to textbooks that remain the primary form of science instruction in elementary classrooms (Bryce, 2011; Ford, 2004; Smolkin, McTigue, Donovan, & Coleman, 2009).

Curriculum Design

The development of each of the PictureSTEM curricular units followed the curriculum design method described by Clements' (2007) Curriculum Research Framework, and occurred in three stages: Stage 1: Initial Development, Stage 2: Pilot and Teaching Experiment, and Stage 3: Classroom Implementation. Stages 2 and 3 of this project will follow a multi-tier design study to investigate the nature of students', teachers', and researchers' developing knowledge and abilities during the development of these STEM integration modules (Lesh & Kelly, 2000). The project has currently completed stage 2 for this unit and will be moving into the third stage during the following school year.

In *Stage 1: Initial Development*, the research team used the research literature relating to the subject matter, types of activities and learning theory models to develop an initial version of the module. Desired content understandings in STEM disciplines and literacy were determined based on national standards in STEM content areas, and a unit theme was chosen. High-quality trade books related to the theme and STEM content knowledge were chosen based on literary quality and accuracy, as determined by literary award criteria. Additionally, an engineering design challenge appropriate for the theme and desired learning outcomes was created. After the development of the engineering design challenge, the individual lessons that support the meaningful learning of the unit outcomes and that provide the understanding necessary to ultimately complete the design challenge were developed.

Stage 2: Curriculum Pilot was comprised of a small pilot study with one teacher in a single classroom. This initial exploration was designed to pilot this module with a teacher who had been through a professional development session on STEM learning and the integration of this curricular unit led by the research team. The piloting of this curricular unit in a single classroom helped to gather feedback on student learning and teaching implementation, and to identify changes that needed to be made before the curriculum was implemented in additional classrooms (Clements, 2007). After revising the curriculum based upon data collected during the pilot, the curriculum was scaled up and tested with a larger number of teachers.

Stage 3: Classroom Implementation will be comprised of several implementations occurring in multiple classrooms by different teachers who have also worked in this university-school partnership. Members of the research team will help to lead the implementation of this curricular unit into these additional classrooms. Data collected from this classroom implementations will be used to in order to get a broader view of the ways in which students learn the desired content and teachers implement the curriculum and to inform revisions for final development and future implementations of this curricular unit.

Participants and Context

This curricular unit was piloted in an urban district in a large, Midwestern city with diverse student demographics. The school district is partnered with a local university through a university-industry partnership. It was implemented with approximately 90 fifth-grade students by one of the fifth grade teachers. The unit is described in detail in the next section. The future directions for this curriculum project are to continue to study how teachers integrate engineering and STEM into their classrooms by examining how the integration of STEM and literacy can be used as a model to enhance STEM learning.

Description of the Unit

This 7-day unit is geared towards the upper elementary grades (4-5), but is also easily adaptable to middle school. It connects learning in the areas of life science, geometry, measurement, data analysis, and engineering design through 7 pairs of literacy and STEM integration activities, each with their own age- and activity-appropriate high-quality trade book (See Figure 1).

Fifth Grade Unit Overview: Nature Inspired Design					
	Day 1 – Biomimicry	**Day 2** – Volume	**Day 3** –Data Analysis & Volume	**Day 4** – What are Adaptations?	**Day 5** – Plant Adaptations
Literacy Activities	Book: *Nature Got There First: Inventions Inspired by Nature* Strategy: Summarize informational text	Book: *For Good Measure* Strategy: Juicy Words- Vocabulary	Book: *Our World of Water: Children and Water Around the World* Strategy: Compare & Contrast	Book: *What do you do When Something Wants to Eat You* Strategy: Making Predictions	Student research on biomes and plant adaptations Strategy: Research Skills
STEM Integration Activities	Students explore an example of nature inspired design before sharing products with classmates	Students learn about volume, liquid volume and how to calculate volume	Students use data analysis and average rainfall data to help inform the size and dimensions for their storage tank	Rotate through stations, where students explore the advantages that different adaptations provide	Students research a biome and plant adaptations before sharing their findings with the class
	Day 6 – Planning your design	**Day 7** – Nature-Inspired Design			
Literacy Activities	Book: Biomimicry: Inventions Inspired by Nature Strategy:	Book: *A Cool Drink of Water* Strategy: Author's Message			
STEM Integration Activities	Students review before the initial brainstorming & planning for engineering design challenge	Create prototype, present to the class and then improve the design			

Figure 1: Design and Layout of the Fifth Grade Module, *Nature-Inspired Design*

Lesson 1 uses the book *Nature Got There First: Inventions Inspired by Nature* to motivate the students to consider how plants and animals gather water and brainstorming some biomimicry ideas of their own. The students are introduced to the design challenge in this lesson:

> A chapter of Engineers without Borders has asked the student teams to help them design a prototype water collection tank for individual families on Isle Popa in Panama. The water collection tanks have two parts, a rectangular prism shaped storage container and a top, which collects the rainwater. In order for these to be useful as well as aesthetically pleasing, the students are to design the top to be efficient and eye pleasing by using nature as their inspiration.

Lesson 2 uses the book, *For Good Measure: The Ways We Say How Much, How Far, How Heavy, How Big, How Old,* and nets and centimeter cubes to develop conceptions of surface area and volume in order to better understand the trade-off of materials vs. dimensions and size for the storage tank portion of the engineering design. Lesson 3 helps students to start to think about water and how different cultures and people collect water by reading the book, *Our World of Water: Children and Water Around the World.* This leads to a lesson on data analysis where students use rainfall data from Isle Popa to decide how much volume the storage container should hold, while the competing variable of cost for materials challenges the idea of making it big. Lesson 4 focuses on animal adaptatations through the book, *What Do You Do When Something Wants to Eat You?,* and rotating through nine stations to explore the different advantages that specific physical adaptations provide to various animals. Lesson 5 has the literacy and STEM lesson integrated by students doing research on specific biomes and the adaptations that plants have developed in order to survive in that biome. Lesson 6 brings students back to the idea of nature-inspired design through a book called *Biomimicry*. Students then use their background knowledge to make a plan for the top water collection portion of the tank. Here they must consider cost, ability and efficiency of collecting water, and size of the top. These represent competing variables in the design. Lesson 7 highlights water through a reading of *A Cool Drink of Water* where students learn about all of the different ways that people get water around the world. Students continue to work on their engineering design challenge by building a prototype for the design plan that they created in the previous lesson. After building their prototype, students are able to test their design to see whether it was successful. After testing their design, students will have a chance to share their initial design with the class before improving and retesting their prototype.

Conclusion

The recently published *Next Generation Science Standards* (NGSS Lead States, 2013) are calling for the integration of science and engineering at the elementary level through the scientific and engineering practices as well as through the disciplinary core ideas. However, there is not an established tradition for integrating engineering at the elementary level and there is limited research in this area. These modules provide some insight into the integration of engineering into elementary classrooms and the role of engineering to assist with the facilitation of STEM learning. Furthermore, these modules provide examples of how literacy could be used to facilitate science and engineering learning in elementary classrooms where time and resources are limited.

As science educators it is important that we are helping to meet this increasing need for integrated learning in science and engineering through research and development of models of STEM learning.

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References

Brophy, S., Klein, S., Portsmore, M. & Rogers, C. (2008). Advancing engineering education in P-12 classroom. *Journal of Engineering Education*, *97*(3), 369-387.

Bryce, N. (2011). Meeting the reading challenges of science textbooks in the primary grades. *Reading Teacher, 64*(7), 474-485.

Clements, D.H. (2007). Curriculum research: Toward a framework for "research-based curricula." *Journal for Research in Mathematics Education, 38*(1), 35-70.

Ford, D. J. (2004). Highly recommended trade books: Can they be used in inquiry science? In E. W. Saul (Ed.), Crossing borders in literacy and science instruction: Perspectiveson theory and practice (pp. 277 – 290). Newark, DE: International Reading Association.

Lesh. R.A., & Kelly, A.E. (2000). Multitiered teaching experiments. In A.E. Kelly & R.A. Lesh (Eds.), *Handbook of research design in mathematics and science education* (pp. 197-230). Mahwah, NJ: L. Erlbaum.

Moore, T.J., Stohlmann, M.S., Wang, H.-H., Tank, K.M., Glancy, A.W., & Roehrig, G.H. (in press). Implementation and integration of engineering in K-12 STEM education. In Ş. Purzer, J. Strobel, & M. Cardella (Eds.), *Engineering in precollege settings: Research into practice.* West Lafayette, IN: Purdue Press.

National Research Council. (2009). *Engineering in K–12 education: Understanding the status and improving the prospects.* Washington, DC: National Academies Press.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

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

Roehrig, G.H., Moore, T.J., Wang, H.-H., & Park, M.S. (2012). Is adding the E enough?: Investigating the impact of K-12 engineering standards on the implementation of STEM integration. *School Science and Mathematics, 112*(1), 31-44.

Smolkin, L. B., McTigue, E. M., Donovan, C. A., & Coleman, J. M. (2009). Explanation in science trade books recommended for use with elementary students. *Science Education, 93*(4), 587-61