



## **The PictureSTEM Project: A Curricular Approach Using Picture Books to Transform STEM Learning in Elementary Classrooms(Curriculum Exchange)**

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## **Introduction**

“Science, engineering, and technology permeate nearly every facet of modern life, and they also hold the key to meeting many of humanity’s most pressing current and future challenges. Yet too few U.S. workers have strong backgrounds in these fields, and many people lack even fundamental knowledge of them.”<sup>1</sup> (pg. 1). This quote echoes the sentiments of recent national documents that have called attention to the need to improve K-12 science and mathematics education in order to motivate more students to pursue STEM fields and to ultimately remain competitive in this increasingly global economy<sup>1-3</sup>. As we look to the future prosperity of our nation, we need to be preparing students for the complex and multidisciplinary problems that face our society today and in the future, and we can help to address this issue by improving students’ learning and experiences in STEM. Furthermore, the integration of STEM disciplines into K-12 education has the potential to markedly increase student interest, motivation and achievement in these fields due to the relevance to real world problem solving<sup>3</sup>. However, when looking at the current structures of STEM learning in K-12 classrooms, the STEM 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<sup>3</sup>. This suggests the need for a new model of STEM learning that attends to the specific content as well as the overarching ideas that integrate the STEM disciplines.

This paper will present one module from the PictureSTEM project, which was developed in order to meet the need for an integrated approach by employing engineering and literary contexts to integrate science, technology, and mathematics instruction in meaningful and significant ways. Since this paper was written for the curriculum exchange, the focus will be on the detailed explanation of each of the activities along with the process used to develop the curricular unit before a brief presentation of results based on the piloting of this curriculum in several primary classrooms.

The theoretical framework guiding the development of the PictureSTEM modules was the STEM Integration research paradigm<sup>4</sup>. Within this paradigm, STEM integration 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<sup>5</sup>. Support for the integration of multiple disciplines has been recognized in national and state standards documents across various disciplines. In

mathematics, the National Council of Teachers of Mathematics (NCTM) states that an important challenge that needs to be addressed is teaching mathematics content in ways that engage students in meaningful, real-world settings<sup>5</sup>. The *Standards for Technological Literacy*, published by the International Technology and Engineering Educators Association<sup>6</sup> also states that learning about technology can and should be integrated into students' learning in multiple subjects. Additionally, the recently published frameworks document for K-12 Science Education states that “engaging in the practices of science and engineering during their K-12 schooling should help students see how science and engineering are instrumental in addressing major challenges that confront society today”<sup>1</sup>. The need for the integration of engineering into the K-12 curriculum has been echoed at the state level with the adoption of explicit engineering standards in 13 states and implicit engineering in 26 states, with many of those appearing at the elementary level<sup>7</sup>. This local and national support for the integration of STEM disciplines provides an opportunity for educators to capitalize on the interdisciplinary nature of STEM fields while crossing traditional discipline boundaries.

Elementary classrooms provide a structure that is advantageous to the meaningful integration of these four STEM disciplines. A single classroom teacher is responsible for teaching multiple content areas within the school day, thus leaving a greater possibility for applying an interdisciplinary approach to teaching STEM disciplines than in the structure of secondary schools where teachers are licensed and departmentalized into isolated STEM disciplines. A look at STEM learning in elementary classrooms, however, reveals that the current implementation does not reflect the interconnectedness of the four STEM disciplines in the natural world<sup>3</sup>. However, providing high-quality STEM learning opportunities continues to be a challenge in the elementary classroom due to a number of factors. Increased demands on teachers, including high stakes testing in reading and math, are resulting in less time for science instruction in elementary classrooms<sup>8</sup>. These are not new challenges for elementary classrooms<sup>9</sup>, however the need for recruiting a knowledgeable and diverse workforce in STEM fields requires that a different approach be taken<sup>2</sup>. 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<sup>10-13</sup>. The PictureSTEM curriculum implements an integration approach through the integration of STEM and literacy instruction. This integration would allow students more time to receive hands-on interdisciplinary instruction in both STEM content and literacy and extend student learning by providing background knowledge and a real-world context that is motivating and engaging for students.

## **Background**

The PictureSTEM units were developed to meet the need for STEM integration modules that meaningfully teach essential core content and cross-disciplinary concepts in STEM disciplines.

Building off the *Framework for Quality STEM Integration Curriculum*, we developed each of these units to intentionally include a motivating and engaging context, meaningful mathematics and science content, student-centered pedagogies, an engineering design task that is driven by a context and involves problem-solving skills, and teamwork and communication skills<sup>14</sup>. Each of the units implement STEM learning by using picture books, STEM activities and an engineering design challenge to provide students with authentic, contextual activities that engage learners in specific STEM content as well as integrate concepts across traditional disciplinary boundaries. Engineering and Literacy were two important contexts used within these STEM integration units to allow for the authentic and meaningful integration of multiple STEM disciplines. 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<sup>15</sup>. The literacy is used as a model of realistic and meaningful integration of the STEM disciplines in elementary classrooms through the literacy lesson followed by a related STEM activity.

### *Engineering as a vehicle for integration*

The engineering component of these lessons helps to tie all of the lessons and learning together by building off the science, technology, and mathematics learning and applying those concepts while learning about engineering through an engineering design challenge. More specifically, the engineering component was based on the findings suggested in the 2009 NRC report, which recommends that K-12 engineering education should emphasize engineering design, developmentally appropriate math, science, and technology skills and promote engineering habits of mind<sup>3</sup>. The recently published *K-12 Framework for Science Education* has promoted a similar vision with the inclusion of engineering as practices in addition to engineering as a disciplinary core idea that highlights engineering design<sup>1</sup>. It has been suggested that in order to get more students interested in STEM fields, students' exposure to engineering should begin in elementary schools to capture interest and dispel common misconceptions of STEM disciplines held by elementary students<sup>3,16</sup>.

The concept of engineering design is addressed at a developmentally appropriate level for the designed unit through an engineering design challenge in which students apply the science and mathematics concepts that they have learned previously. 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”<sup>3</sup>(p.4). Additionally, the engineering component allows students the opportunity to start developing certain aspects of engineering “habits of mind”, based on the grade and developmental level of the specific unit. Engineering “habits of mind” refers to the values, attitudes, and thinking skills associated with engineering and includes systems thinking, creativity, optimism, collaboration, communication, and an attention to ethical considerations<sup>3</sup>.

### *Using Literacy to Support STEM Learning*

The literacy component builds upon the idea of integrating across disciplines by using high-quality science and mathematics trade books to enhance and extend instruction, which helps students to make connections across disciplines and with the realistic context for student learning. The common core standards for English Language Arts identifies that “reading is critical to building knowledge in history/social studies as well as in science and technical subjects and that these reading standards are meant to complement the specific content demands of the disciplines, not replace them”<sup>17</sup>. Research in the area of science and literacy integration has found the increase in student achievement and motivation in science, reading and writing with the implementation of integrated science and literacy instruction<sup>10-13</sup>. The use of trade books in these units, provide up-to-date content that is more engaging, relevant, and accessible due to the due to excellent visual features and high-quality writing when compared to textbooks that remain the primary form of science instruction in elementary classrooms<sup>18-21</sup>. The use of science trade books in these units provides students with background knowledge and a context that helps to facilitate the STEM learning that is intentionally tied to these literacy lessons. Building upon the research on the efficacy of integrating science and literacy, the PictureSTEM units provide opportunities to cross the discipline-specific boundaries by meaningfully integrating across all four STEM disciplines and literacy to foster the interconnectedness of real-world problems.

### **Curriculum Design and Methodology**

The development of this PictureSTEM curricular unit followed the curriculum design method described by Clements’ (2007) Curriculum Research Framework,<sup>22</sup> 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 used 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<sup>23</sup>.

In *Stage 1: Initial Development*, the research team used what is already known in terms of 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* was comprised of additional implementations occurring in multiple classrooms by different teachers who had also participated in a summer professional development focused on STEM learning. Members of the research team led the integration of this curricular unit into these additional classrooms. These additional teachers and implementations were included in the study in order to get a broader view of the ways in which students learn the desired content and teachers implement the curriculum. The data that was collected from the classroom implementations will be used to inform revisions for the final development and future implementations of this curricular unit.

### Participants and Context

This early elementary curricular unit was piloted in kindergarten, first, and second grade classrooms in two urban districts in a large, Midwestern city with similar student demographics. Both school districts are partnered with a large, public university through a university-industry-school district partnership. It was implemented with 120 kindergarteners and 600 first graders in 10 different elementary schools. Data was collected during each stage of implementation, however, it is still in preliminary stages of analysis.

### Description of the Unit

This unit is geared towards the early elementary grades (K-2) and consists of five pairs of literacy and STEM integration activities, each of which requires approximately 30 minutes of class time. The intent was that these modules would be flexible enough for teachers to choose to teach either one activity or one pair of activities each day, depending on what works best for their schedules and their students. However, in this paper we consider each day's activity to be the combination of one literacy and one STEM integration lesson. The picture books, literacy and STEM integration activities included in this early elementary module are summarized in Table 1 below.

Table 1: Design and Layout of the First Grade Module

Sample First Grade Module: Designing Animal Habitats					
	Day 1 - Animals	Day 2 – Animal Habitats	Day 3 – Shapes and Animals	Day 4 – Designing your Habitat	Day 5 – Testing your Habitat
Literacy Focus: Suggested guided reading: animals, habitats	Book: <i>Is my Hamster Wild?</i>  Strategy: Main Idea from Informational Text	Book: <i>Magic School Bus Hops Home</i>  Strategy: Making Connections – Human and animal homes	Book: <i>Three Pigs, One Wolf and 7 Magic Shapes</i>  Strategy: Comprehension Monitoring: Questioning	Book: <i>Leo Cockroach... Toy Tester</i>  Strategy: Fiction & Vocabulary – using “Juicy Words”	Book: <i>The Perfect Pet</i>  Strategy: Identifying important details
STEM integration activities	Identify animals’ basic needs  Sort animals by characteristics and basic needs.	Looking at how habitats provide for animals’ basic needs. Using pattern blocks to identify places where needs are met	Students create the animals in the story above with tangrams, and then create some on their own.	Introduce engineering and the engineering design cycle. Plan the hamster habitat and how many pieces are needed.	Build and test a hamster exercise habitat trail using 3-D geometric shapes that will meet the hamster’s basic needs.

Animals and their homes are a high-interest topic for younger children, and this unit, *Designing Animal Habitats*, allows children the opportunity to think like engineers as they design a habitat for an imaginary pet hamster. Constraints are put upon their design, including requiring the students to use exactly 20, connected, three-dimensional shapes to form an exercise habitat tube trail and to incorporate components that would meet the hamster’s need for food, water, shelter, and fresh air. These constraints are directly related to the mathematics and science concepts taught in the unit. These STEM-related lessons are all paired with a literacy lesson, each with their own age- and activity-appropriate trade book.

The unit begins with a whole-class reading of the book, *Is My Hamster Wild?: The Secret Lives of Hamsters, Gerbils, and Guinea Pigs*<sup>24</sup>. This non-fiction text introduces students to the lives and habitats of these rodents in nature and describes similarities between how the animals may act when observed as pets to how they act in the wild. The proposed reading comprehension skill to be taught during the literacy portion of the lesson is finding the main idea from informational text. The information that students learn about hamsters helps create context for the final design challenge. It also builds background knowledge for that day’s corresponding STEM integration activity, which involves sorting and classifying animals in two different ways,

first by their characteristics and then by their basic needs. The sorting and classifying activities reinforce the content from the literacy lesson and build important math and science content skills, according to national standards documents in both areas. Table 2 shows specific content standards in literacy, mathematics, science, and engineering/technology that are met by activities in the unit.

Table 2: STEM and Literacy Content Connections and Standards

<b>Content Area</b>	<b>Learning Activities</b>	<b>Standards</b>
<b>Literacy</b>	Main idea and details from informational text, making connections, vocabulary, questioning	<b><i>Common Core Standards for English Language Arts</i><sup>17</sup></b> 1.1.2.2 – Retell stories, including key details. 1.2.1.1 – Identify main topic and key details of a text 1.2.8.8 – Identify the reasons an author gives to support points in a text.
<b>Science</b>	Animals, habitats and basic needs, designed and natural systems	<b><i>NSES Teaching Standards (NRC)</i><sup>25</sup></b> - Standard B: Teachers of science guide and facilitate learning  <b><i>NSES Content Standards (NRC)</i><sup>25</sup></b> – Grade K-4, Standard C: Life Science, Organisms and Environments; Standard E: Science and Technology
<b>Engineering &amp; Technology</b>	Engineering design process, testing materials Designed habitats and “cage” components	<b><i>National Standards (ITEEA)</i><sup>6</sup></b> – Standard 3: Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study. Standard 9: Students will develop an understanding of engineering design.
<b>Mathematics</b>	Characteristics of basic shapes and use those to compose and decompose objects, measurements with emphasis on making 20	<b><i>National Standards (NCTM)</i><sup>5</sup></b> - •Recognize, name, build, draw, compare, sort two- and three-dimensional shapes; •Describe attributes of two- and three-dimensional shapes; <b><i>Common Core Standards for Mathematics</i><sup>17</sup></b> 1.OA – Operations: Add and subtract within 20 1.G – Geometry: Reason with shapes and their attributes

The second day’s literacy lesson uses the book, *The Magic School Bus Hops Home*<sup>26</sup>, and asks students to make connections between the characteristics of human and animal homes, which leads to the idea that habitats should meet their occupants’ basic needs. The corresponding STEM integration activity then has students examining pictures of different habitats for a variety of animals and identifying places in those habitats that meet the animal’s basic needs.

The third day departs from the animal habitat theme and focuses on developing the mathematics shape recognition and spatial skills necessary to complete the design challenge. The literacy



lesson builds on students' definitions of basic two-dimensional shapes through the story of *The Greedy Triangle*<sup>27</sup>, in which a triangle visits a shape shifter to add sides and angles and in order to become different shapes. The STEM activity provides a foundation for the idea of shape rotation that allows students to understand that shapes to fit together in different ways, which is a concept that students must use when creating their exercise habitat trails for the engineering design challenge. After a whole class reading of the book, *Three Pigs, One Wolf and 7 Magic Shapes*<sup>28</sup>, students use tangram pieces to recreate the shapes shown in the story.

The focus of Day 4 is learning about engineering and the engineering design cycle. The story for this day, *Leo Cockroach...Toy Tester*<sup>29</sup>, features a fictional cockroach who takes it upon himself to test toys for a toy company. Throughout the story, he models why testing is an important component of engineering design, helping students to see the need for testing their materials before creating their habitat trail designs. Students are told they will be creating the model of a hamster exercise habitat trail using exactly 20 three-dimensional shapes called Geosolids™. These shapes may be laid next to one another or stacked to create an interesting habitat trail for the hamster. To prepare for this design challenge, students are asked to think like engineers (and Leo Cockroach) while they test these Geosolids™ for “flickability” and “stackability.” The flickability test has students observing what happens when they (gently!) flick the different shapes, particularly noting which shapes roll away and which shapes do not. The stackability test has students stacking different combinations of the shapes to determine which shapes may be stacked, and whether orientation of those shapes affects their stackability.

The final lessons of the unit return to the notion of animal habitats and animal's basic needs. The picture book, *The Perfect Pet*<sup>26</sup>, tells the story of a fictional young girl who tries to persuade her parents to buy her several different pets. Her parents respond by pointing out how each animal has needs that make it a poor choice for her pet. Following the reading of the story, students brainstorm the needs of a pet hamster, and then work in pairs to plan and create their exercise habitat trails. Alongside the habitat trail, using the same shapes as they used on Day 2, they indicate where the hamster would find food, water, and a safe place to sleep. Pairs then test their models by moving pictures of a hamster along the trail, pretending to let the hamster eat, drink, and rest at the appropriate points as a way of checking that the habitat trail will meet the hamster's basic needs, and pretending to let the hamster escape through any holes or gaps in the trail. After sharing their designs with their classmates, students are given the opportunity to redesign their trails, fixing any areas in which the original design challenge requirements were not met, and test their new designs as before. The final redesign and test phase takes only a short time but provides a critical learning opportunity for students to experience the iterative nature of engineering design.

## Results

Preliminary results from the kindergarten, first, and second grade teachers who have used the curriculum are very positive. The interview data revealed that both the teachers and the students involved in the piloting of this unit were enthusiastic about the unit and the content and activities involved. Students and teachers repeatedly mentioned the engineering design challenge as the part of unit that was very engaging and motivating. In the words of one teacher, “The students just loved the engineering challenge and they did awesome on it.” Overall, teachers found that students were very engaged in the context of designing a habitat for their pet hamster, and they were able to use their creativity and imagination to come up with a number of unique designs, which they would readily explain to anyone who would listen. The teachers also had positive things to say about the unit and how their students were able to understand and apply the science and mathematics concepts through their designs and redesigns. Through an oral assessment of the science and mathematics content covered in this unit and administered by the teachers, they reported that their students were able to explain the concepts of basic needs and habitats by the end of the lesson and even apply their understanding of habitats and 3D shapes in other contexts. For example, students in one kindergarten class surprised a naturalist while on a field trip by correctly using the term “animal habitat.” During a later science unit, those same students noted that adding things to a fish’s aquarium affected the fish’s “habitat,” thereby demonstrating that they had gained a deep and flexible understanding of the term and why it is important to animals. That same teacher also noted in her interview that her students outperformed previous years’ classes on a year-end assessment of their three-dimensional shape recognition skills, which the teacher attributed to their work with the shapes during this unit.

The teachers also reported that the literacy connection of the use of science and mathematics picture books were enjoyed by the children and provided appropriate context for the discussion of each day’s STEM-integration activities. Several teachers found that the books provided a broader perspective on the content by helping students to make connections to other content they had learned both prior to and following the unit. One teacher noted that the reading and discussion of frogs and their habitats in the Day Two literacy activity helped to extend the concept of animal habitats beyond hamsters and that was reinforced with the sorting and identifying of different animals and animal habitats.

The piloting of this curriculum in several classrooms provided some helpful insight into improvements that can be made and points to consider for future curricular units. One simple modification made by one of the kindergarten teachers was to have the students do the “stackability” and “flickability” in the lid of a copy paper box to help keep the shapes from ending up all over the classroom. The introduction of a “shapes store” by a few of the teachers helped to make their first graders a little more intentional about the shapes and less likely to tinker with the shapes as they were building their designs. The addition of the shapes store is

included in the most recent version of the module plans. When reflecting on developmentally appropriate learning progressions for engineering design with five, six and seven- year olds, we found that the kindergarteners were able to understand the importance of testing materials before designing and why engineers improve and redesign. The drawing up of a plan was difficult for the kindergarteners, but several teachers found that a helpful modification was to have their students focus on the number of each shape they needed as the planning step before visiting a “shape store” to obtain their 20 shapes. The focus on determining the necessary materials and verbally planning their habitat was a developmentally appropriate modification that introduced younger students to the idea that there is a process that is followed when designing a solution to their problem.

## **Conclusion**

When thinking about implementing engineering into the elementary classroom it is important to consider how these lessons are presenting engineering and STEM, as a connected and integrated entity or as a set of single subjects. This Designing Hamster Habitat module presented activities and ideas as interdisciplinary and integrated across STEM content areas. Through the implementation of this module, we found that early elementary students were able to make connections between the disciplines and gain a deeper understanding of the content ideas. Additionally, the students were able to apply what they learned during this unit in other contexts, such as during a science unit where they learned about caring for their goldfish and how to meet the needs of their goldfish. When asked about the literacy component, the teachers found that the picture books provided a realistic and engaging context in which to situate their students’ learning of the STEM concepts.

We know that one concern that teachers have as they consider how to incorporate engineering into their early elementary classrooms is time. Teaching engineering units does take time, but as demonstrated by the students’ understanding of animal habitats and three-dimensional shapes, introducing young children to engineering and engineering design through this literature-enhanced STEM integration unit can be a great way to facilitate connections between science, mathematics and engineering in a way that is meaningful and engaging to students.

This curricular unit provides an important model of STEM learning and STEM integration that may motivate more students to pursue STEM fields and to help develop learners with understandings, skills, habits of mind and dispositions to engage in scientific, technical, engineering, and mathematical thinking and practices. In this paper, we are suggesting that STEM integration modules tied to literacy instruction have the potential as a new model for STEM learning environments, especially at the elementary level where no current curriculum meaningfully integrates STEM across content standards.

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 in different classrooms across the elementary grades.

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