The Structure of a Story

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Abstract – **The stories of engineering heroes can serve as an exciting means of engaging young students in engineering concepts that are linked to their math and science curriculum. This research explores the development of a storytelling framework including the story of an engineer, a hands-on activity for exploring a related engineering idea, reinforcement of standard math and science curriculum and assessment of the effectiveness of the storytelling medium to teach and inspire young students. Storytelling principles are used to develop these narratives into compelling and engaging stories through the perspective of an individual character. Archival and other scholarly materials on fascinating figures in engineering are used to construct the stories. Following the story, a hands-on activity supports the exploration of the engineering concept related to the engineer's story. A pre- and post-story test are used to assess the effectiveness of the story and activity to learn about what engineers do, and the specific engineering idea.**

Index Terms – arches, K-12 education, storytelling, structural engineering, tower.

INTRODUCTION

"Once upon a time, engineers knew the stories of the heroes in their profession…. " As with most tales, there are elements of truth hidden within the previous statement, regardless of its historical accuracy or lack thereof. What is indisputable is that today's engineers and engineering students are woefully unaware of the grand tradition of engineering and of the fascinating and important people associated with seminal engineering ideas. Compare today's engineering student's lack of understanding of the colorful characters and stories in the history of engineering with the typical architecture student's or art student's knowledge of the major figures in their professions. Each architecture student could easily name ten or twenty major architects, each art student could also name this many artists and describe what their contributions were at least in an elementary manner. Furthermore, few elementary and secondary students can describe what an engineer does or how an engineer contributes to society. Being unaware of what engineering looks and feels like may explain why many students have no interest in pursuing engineering. These voids beckoned us to begin this research. We began with the idea that the stories of the heroes of our profession are a natural starting point in the transmission of a fundamental engineering idea. This thought process led to a research program recently undertaken in the Architectural Engineering Department of our university that seeks to introduce and excite K-12 students about structural engineering ideas using the medium of storytelling. This research program establishes a storytelling framework which introduces an engineering idea, explores this in an activity and provides relevance for appropriate curricular principles in math and science.

BACKGROUND TO OUR RESEARCH

I. Story

A story is a specific narrative form that provides an account of a series of events that are linked together, usually through a cast of characters. The story has a beginning and an end. Haven [1] simply states the essential components of story are characters, conflicts, struggles and goals. A dynamic and engaging story poses a dilemma or conflict that must be resolved. Characters encounter barriers to achieve their goals. Our interpretation of "story" in this research project is further informed by previous studies on the effectiveness of storytelling [2]. Numerous studies have explored storytelling to communicate science concepts to children. Hadzigeoriou [3] and Isabelle [4] employ storytelling to humanize the discovery of electrical currents and explain the concept of air pressure.

We have used the previous studies to help us formulate the structure of story that could be used to convey a fundamental engineering idea. We reasoned that by linking the idea to a historical engineer, we would engage the children more fully and hopefully we would inspire them. This personalization of the engineering idea would presumably leave a deeper impression in the children, than a simpler, traditional explanation of the idea itself. There are at least two intuitive arguments supporting this approach; one is the timeless oral tradition of passing down ideas through a recited story, the second is the pedagogical argument of contextualizing. "Contextual Learning" has garnered much scholarly attention recently [5], and it has gained credence in the engineering community because of research that supports the thesis that students learn when they can internalize a subject and process it through the prism of their own experiences [6]. Such personalization, or contextualizing forms the pedagogical basis for "Project Based Learning" and case-studies in higher education. [7]

In our research, we have contextualized an engineering principle by tying it to a specific historical figure, and presenting the engineering principle and the person in a story format. The story can have pseudo-realistic dialogue, and fabricated secondary characters and events, yet it clearly cannot be fiction. We insisted on using archival and other scholarly material to form the basis of the story, then we embellished as we saw fit, in order to create a lively, brief narrative suitable for 5^{th} or 6^{th} grade children.

Further, we imposed upon ourselves the requirement that we convey the nucleus of an engineering formula. The details of the formula need not be presented in the story, as these were more fully explored in an associated activity to be explored after the story. We were also certain to include story information about the process of engineering. What does it look like and feel like? We wanted the students to grasp the creative genius of an engineer who seeks to invent things that are needed; that engineering is not simply fortuitous discovery. Great determination and work are required to bring the engineer's vision into physical being as well. There is adventure in doing engineering, and we wanted the students to appreciate not only the accomplishment of the engineering feat but the difficulty, importance, nature and scope of past great engineered structures. We wanted the story to convey the importance of these to our modern lives and to see the relationship with science and math. All of this in a single story!

We hoped that the coupling of a historical figure to a specific engineering idea would empower the children to imagine themselves someday as building design professionals, the theory being that a "story provides a map of possible roles and possible worlds in which action, thought and self-definition are possible or desirable" [8]. We are convinced that the substantive literature of storytelling to communicate math and science concepts derives from this very notion.

II. Lesson Framework

We realized that the story needed to be part of a larger lesson framework. To stimulate imagination and engage children's conceptual abilities, the lesson framework was also viewed as a story. Egan [9] states "the purpose is to shape the lesson or unit to use the engaging power of the story form and to ensure that the most important meanings inherent in the content are communicated." The lesson narrative began by establishing a dilemma. The dilemma was carefully selected as it established the rhythm to the lesson. In our case, we posed each lesson dilemma as a question. To explore the dilemma, binary concepts were used to frame the topic. These concepts supplied the lesson with a dynamic tension – polar perspectives, opposing values, resisting forces. The strength of opposition selected for this tension will depend on the developed ability of the student to differentiate between them. In our lessons greater distinctions between binary pairs were drawn for the younger students; less distinct differences need be drawn for older students.

Specific content was chosen based on our binary concepts. We selected this content to elaborate on the dilemma but ensured that only meaningful elements were incorporated. This resulted in simplifying and clarifying our view of content – not "material to be covered", but purposeful ideas that contributed to the exploration of the topic framed by the binary concepts. Content material contrasted the ways in which the concepts were different, and ways in which they were the same. We also built in affective responses to aspects of the lesson; feelings to humanize the topic. Our desire was to focus and power the movement in the lesson toward the central task of solving the conflict. As in a story, the lesson concluded with a resolution to the dilemma. A satisfying conclusion was achieved by aligning with one or the other of the binary concepts, or by mediating a solution between them.

This overarching method is the basis of several approaches applied to math and science teaching including the 5E instructional model for science learning [10] and the Launch Explore Summarize (LES) model applied to mathematics [11]. The 5E model employs engagement, exploration, explaining, elaborating and evaluating. The LES model condenses these steps. Elements of the models as they apply to this work will be described below.

Our framework employed three distinct lesson phases. Pre-story activities were designed to engage the learner in the topic, draw out student's prior knowledge and introduce topic specific vocabulary – the stage was set! The central phase incorporated the story of an engineer and the engineering feat along with a carefully structured activity to explore the central topic. The final phase summarized the key topic and assessed the lesson learning.

The lesson was launched with pictures, models and a small activity to heighten anticipation for the engineering concept. These tools were intended to engage the students in the subject and put them in the mind set for further exploration. Questions were posed surrounding the topic and students were asked to predict what the focal point of the lesson will be. For the purposes of the research, a pretest was given to evaluate prior knowledge on the subject and to serve as a quantitative benchmark on how effective the lesson was for teaching the topic. This phase also introduced key vocabulary. Initially the students were asked to interpret and describe the terms and ideas in their own words. This process was used as a qualitative interactive assessment of their prior knowledge about the concept to be presented. The vocabulary was then clarified through images and activities they could understand and were familiar with.

We then told the story. The story itself introduced the idea in a historical context. We posed the need for the engineering feat in the form of a dilemma. How can a stable arch be constructed? How can a tall tower stand up against wind loads? We explained the engineer's approach and work in relation to the design and construction of the structure. Following the presentation of the story we discussed key aspects to assess whether students understood the content before moving them forward. We reviewed the specific characters and events of the story by asking the students questions. What steps did the engineer have to take to realize the structure? What struggles did the engineer have? What was the most difficult issue for the engineer to address?

To elaborate on the concept, students were then divided into groups. They were referred back to the pre-story activity and vocabulary, and introduced to the idea of exploring the central topic further. A physical model was presented to each group. In a directed way, we allowed students to explore the concept through the model. An equation was introduced to give mathematical representation to the experiment. Multiple variables were explored and we emphasized that in engineering there is not one single solution. We drew connections between the pre-story exercise, the story and the activity. The students were asked to present the results of their study.

The post-story phase included restating the concept, summarizing the results graphically, testing the student's understanding of the learning and providing an opportunity to extend the information further. A summary of the study was provided along with additional resources for exploration.

To study the story/activity concept and lesson framework Architectural Engineering students from our university volunteered in elementary classrooms to present a lesson on a famous engineer. The specific applications and results of these demonstrations are presented.

ENGINEERING LESSON EXAMPLES

We used the previously described story template and lesson framework to teach two different structural topics incorporating two different historical figures, Rafael Guastavino and Gustave Eiffel. Guastavino was a builder/engineer who was responsible for nearly one thousand masonry structures along the East Coast of the United States, most were built in the early 20th century. Eiffel was the premier design engineer in late 19th century France. Both were colorful characters and much scholarly and archival material exists to support the creation of suitable stories for children.

Material for the Rafael Guastavino story was gathered from the Maillart Archives at Princeton University and the Guastavino/Collins Archive of Avery Library at Columbia University. Other scholarly studies [12][13] were also used as well as a memoir by Guastavino's grandson [14]. The purpose of this rather extensive literature search was to ensure that we portrayed the life and times of Guastavino succinctly, but accurately. We also referenced Guastavino's own writings [15] to describe an engineering formula that he used to calculate the minimum required thickness of his masonry arches. We rewrote the original equation in a slightly more "user friendly" format such that the children could understand the physical meaning of each term. The straightforward equation we used was as in (1)

$$T \cdot C = \frac{L \cdot S^2}{8 \cdot r} \qquad (1)$$

T = thickness at crown of the arch (in.)
C = compressive strength parameter of tiles (2060 lbf/in.^{2})
L = loading on arch (lbf/ft)
S = span of arch (ft)
r = rise of arch (ft)

This is the equation describing the axial stress at the apex of a three hinged, (statically determinate) arch. We alluded to this equation in the story that was read to the children. Guastavino must use the equation to resolve the central dilemma -- proving the strength of the arch to carry loads. Opposing concepts of strength/weakness and thin/thick are accentuated. The students explored the equation in detail in the activity which followed the reading of the story. The activity also allowed them to explore a physical (plastic) model of a continuous arch, which they could compress with their hands or with a "loading log" which simulated a uniformly distributed load via a plastic bag filled with sand, Figure 1. The children measured the unloaded span of the arch, then loaded it and measured the now greater distance between the supports, due to the sprawl of the arch under load. This movement of the arch was discussed with the children and we told them that some kind of buttressing would be needed to support the arch at its base, to keep it from sprawling. We then described how structural engineers use equations to calculate the magnitude of those supporting forces and to calculate the required thickness of the arch, which naturally led to the previously described equation. We concluded the activity with an assessment that asked the children to identify terms of the equation, to draw an arch under loading, and to brainstorm about what the influence would be of doubling a parameter (load for example, or span as another example). The purpose of this question was to probe their ability to envision the broader applicability of an engineering equation. To fire their imaginations we also asked them an open-ended question wherein they were to visualize themselves as an engineer in a creative setting.

FIGURE 1
ARCH ACTIVITY

In a similar manner we developed the story of Eiffel and his tower using as a basis the excellent biography by

Loyrette [16] and more recent articles investigating mathematical formulas for the tower shape [17][18]. The tower shape and its relation to lateral load resistance is the focus of the story. For the children this concept is simplified by examining the distance between the legs of the tower and the forces in the legs when lateral load is applied at the tower top.

As in the lesson on Guastavino, a pre-story activity, vocabulary and pretest initiate the lesson followed by the story itself and a more involved activity. A final summary and assessment conclude the lesson.

ASSESSMENT

In a pre-test when students were queried as to whether they knew what an engineer did they responded as follows: Designs 0.07 (4/57), Builds/Constructs 0.25 (14/57), Repairs things 0.14 (8/57) and Don't know 0.54 (31/57). After the lesson students were asked "Do you know what an engineer does? If yes, explain." The replied as follows: Designs 0.2 (8/40), Builds/Constructs 0.52 (21/40), Repairs things 0.07 (3/40), Studies/Draws 0.07 (3/40) and Don't know 0.13 (5/40). Figure 2 graphically shows the data and an increase in the students' awareness of the role of engineers.

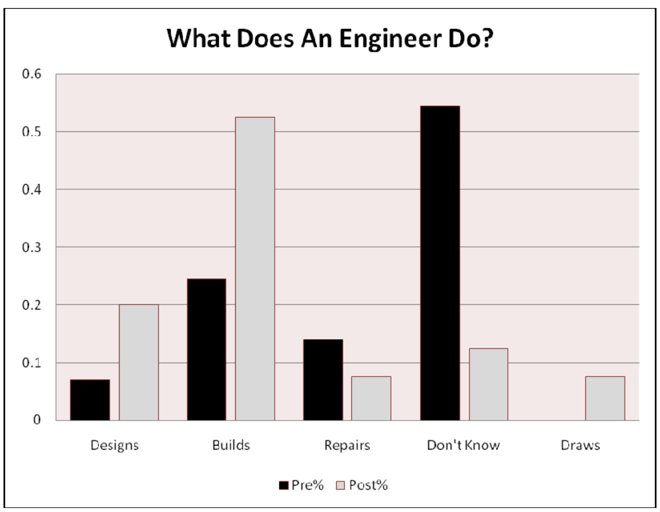

FIGURE 2
PRE-STORY AND POST-STORY TEST RESULTS

We continue to refine the lessons based on the classroom demonstrations. Our future work will explore the effectiveness of the story structure in a diversity of classrooms. Ultimately, we envision providing the teacher with all materials to present the lesson in its entirety. We are currently seeking funding to undertake a more comprehensive multi-variable research study to evaluate the specific effectiveness of the overall framework and modes of presenting the lesson. The importance of framework components will be assessed by employing different combinations and schedules for pre-story, central story and activity and post-story phases. To investigate the effectiveness of different modes of presentation we plan to experiment with instances of an oral story-teller, a reading teacher-teller and simply having the students read the written story. These studies will ensure the memories of the giants in engineering will "live happily ever after. "

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