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Developing Transmedia Engineering Curricula using Cognitive Tools to Impact Learning and the Development of STEM Identity (RTP)

I. Abstract

This paper examines the use of Imaginative Education (IE) to create an NGSS-aligned middle school engineering curriculum that supports transfer and the development of STEM identity. In IE, cognitive tools—such as developmentally appropriate narratives, mysteries and fantasies—are used to design learning environments that both engage learners and help them organize knowledge productively. We have combined IE with transmedia storytelling to develop two multi-week engineering units and six shorter engineering lessons. An overview of the curriculum developed to date and a more detailed description of the engineering design unit is presented in this paper.

The curriculum is currently being implemented in treatment and non-treatment classrooms in middle schools throughout the Springfield, MA public school system (SPS). In tandem with pilot-year implementation of the curriculum, we have developed an assessment instrument to measure student learning outcomes associated with a transfer variant known as preparation for future learning (PFL). An analysis of the results from the PFL assessment support the position that a curriculum employing IE cognitive tools can facilitate both *transfer-in* thinking and the capacity of students to "think with" and thereby interpret important engineering concepts.

II. Introduction

Engineering in K-12 Education

The National Research Council (NRC) reports that the U.S. "will need a steady supply of well-trained engineers, scientists, and other technical workers...to succeed and prosper in the twenty-first century." [1] Because our society is becoming increasingly dependent on engineering and technological advances, it is also recognized that all citizens need to have a basic understanding of engineering processes to make informed choices and understand our world. To address these needs there has been a growing nationwide interest to include engineering in both formal and informal pre-college education. In reviewing early attempts at K-12 engineering education, the NRC found that including engineering in K-12 education has numerous benefits including: improved learning and achievement in science and mathematics; increased awareness of engineering and the work of engineers; understanding of and the ability to engage in engineering design; interest in pursuing engineering as a career; and increased technological literacy. [2]

Initially individual states led the effort to include engineering in K-12 education. More recently attention has shifted to the national level by integrating engineering design into the Next Generation Science Standards (NGSS) at the same level as scientific inquiry. The NRC notes that the insight and interest students gain from this integration should "help students see how science and engineering are instrumental in addressing major challenges that confront society today…" [1]

While including engineering design in NGSS can potentially transform K-12 science education, the resources available to teachers for implementing this approach are still largely undeveloped. The curriculum presented in this paper goes beyond the current practice by applying research from the learning sciences to:

- Frame curriculum units and lessons using dynamic narratives and other cognitive tools;
- Deliver these narratives through transmedia storytelling, in which students become characters in immersive experiences spread over multiple media formats; and
- Integrate science and engineering in a way that is consistent with NGSS.

Engaging Students through Imaginative Education

The engineering education literature has long recognized the need to rethink how students engage with content.[3] Many have raised concerns that reductionist engineering courses that omit intellectual and sociopolitical histories help discourage women from scientific fields.[4-6] Others provide examples of how using storytelling can successfully address these concerns in engineering education at a variety of grade levels.[7-13]

The curriculum presented in this paper is based on the theory of Imaginative Education (IE) developed by Kieran Egan.[14-18] Egan's approach builds on learners' characteristic ways of thinking to structure their engagement with ideas and knowledge. His intent is to engage learners' imaginations in their pursuit of understanding and thus engender the kind of caring about learning necessary for developing learners' capacities to engage in deep learning.

In the IE approach, instruction is designed to support a developmental sequence of five different types of understanding that enable learners to make sense of the world in different ways. Each understanding includes an array of cognitive tools. The most important of these tools is the use of narrative. Bereiter writes that "narratives…create in the reader the experience of significant conditions and events. When in the grip of a story, people don't think, 'How is this relevant to me and my problems?' Instead they experience events through the protagonists…" [19] Researchers in cognitive psychology have learned that stories—both the ones stored in our memories and those we generate as we interact with the world—are essential to all aspects of learning and have long been used as a tool for communicating understanding to students.[20] They are the primary means learners have of relating their existing knowledge to the new ideas they are learning[21] and to express their understanding of the world.[22] They ground complicated concepts in concrete terms and connect abstract ideas with emotions and events.[23] According to IE theory, the narrative structures most appropriate for middle school build on two of the five types of understanding described by Egan: mythic understanding (including the use of fantasy and mystery) and romantic understanding (including exploring limits and extremes of reality and identifying with heroes and heroines).

A Transmedia Approach to IE Narratives

Transmedia storytelling is "a process where integral elements of fiction get dispersed systematically across multiple delivery channels for the purpose of creating a unified and coordinated entertainment experience." [24] Videos; websites; blogs; social media; photos, art, and diagrams; newspaper/magazine articles; journal entries; transcripts of phone calls or videos; documents and records; books or stories; and radio/audio clips are all forms of media used by transmedia storytellers. When using transmedia to create learning environments, research has shown the importance of learners engaging in *transmedia play.*[25] In transmedia play learners go beyond being merely consumers of information and instead become participants who create "new information through connections, explorations, and other forms of imaginative--and productive—play." [26]

The impact of transmedia is similar to IE: "Transmedia consumers are more involved in the story...resulting in more engagement, intrinsic motivation, and media enjoyment." [27] Additionally, "High engagement and media enjoyment result in children's more elaboratively processing information and thus encourage self-regulated learning." [27] The benefits of using transmedia go beyond increased engagement. One is the variety of literacies transmedia environments support, "including textual, visual, and media literacies, as well as multiple intelligences…[it] allows for important social sharing among collaborators." [28] Additionally, "children must learn to read both written and multimedia texts broadly (across multiple media) and deeply (digging into details of the narrative)." [28]

III. Applying IE to Create a Student Learning Website (goteems.org)

This paper presents a transmedia engineering curriculum called Transforming Engineering Education for Middle Schools (TEEMS) that is structured around narratives and other IE cognitive tools. Aligned with NGSS and designed for the sixth-grade, the TEEMS curriculum is available online through a multimedia, interactive platform in which students become immersed in the narrative adventures. Half-finished now, it will be completed by summer, 2020. The site already includes a multi-week unit introducing engineering design and three additional lessons that apply engineering design in different contexts.

The Survivorama Unit

The Survivorama unit aligns with the Next Generation Science Standards (NGSS) for MS-ETS1 Engineering Design. The unit introduces students to the engineering design cycle through the story of Monet, an intrepid 17-year-old who takes on a bio-tech company with evil plans: to generate extreme, un-survivable weather all over the planet. In this two-week unit students:

- Learn about engineering design through engaging with a dystopian narrative that leads to creating their own engineering design cycle;
- Help Monet fight Collusia by designing bio-armor that can survive any condition;
- Explore the design cycle more deeply by identifying the design failures in a real-life case study; and
- apply their knowledge by engaging in a design challenge.

The flow of the unit is illustrated in Figure 1.

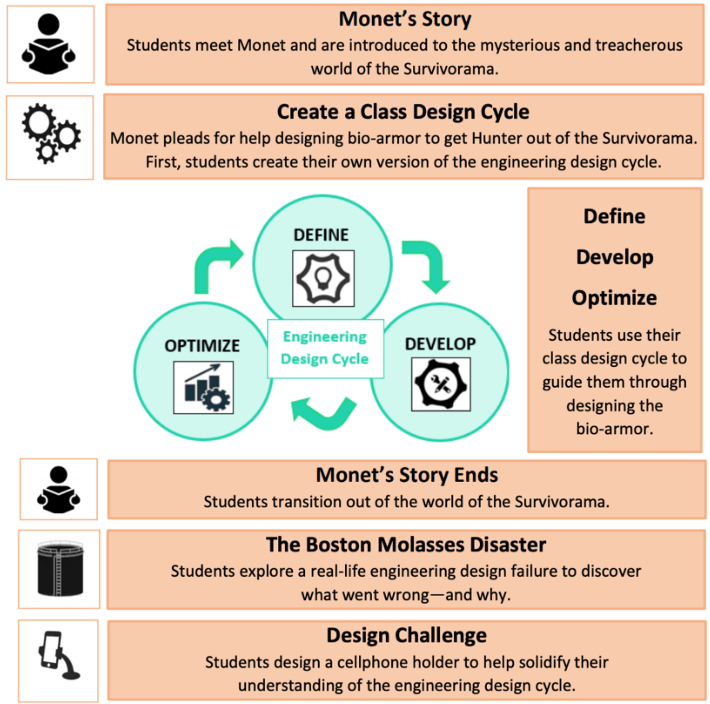

Figure 1: Flow of Survivorama Unit

Monet's Story

Through video and a variety of online resources, students are introduced to the story of the Survivorama that frames the unit.

> Storyline: Monet designs landscapes for the Survivorama, a big dome where the company creates extreme weather conditions. In the Survivorama, "testers" try out tough armor – the SuperSuit – to see if it protects them from environmental disasters. But one day Monet's access to the dome is cut off without explanation. Then a co-worker named Hunter appears and shows Monet a hacked email that reveals a horrible secret: Lisa, the Collusia's CEO, plans to create extreme weather all over the planet so that everyone needs her SuperSuit – and she'll be rich. When Hunter disappears, Monet discovers a mysterious flash drive in his empty office. She finally finds Hunter locked in the Survivorama with no SuperSuit to protect him. She must go on the run … but she vows to return and rescue Hunter.

Create a Class Design Cycle

Now immersed in the storyline, students become active participants by working together to build the engineering design cycle based on pieces of information they discover in Hunter's logbook. These include an old video he found showing designers from the past working successfully through a design cycle and his notes about the video.

> Storyline: Monet is ready to return to the Survivorama and rescue Hunter. She has an idea about how he can survive the tough conditions in the dome: design bio-armor (something even better than Lisa's SuperSuit). But she needs help!

Monet believes that there may be key ideas about design in the files Hunter left behind on his flash drive.

Define

Students apply what they have learned about the define phase of the design cycle to identify the problem they want to solve and describe the user's needs. Students explore all the resources to identify the needs for the bio-armor. Resources include voicemails, hacked emails, and a Survivorama map showing Hunter's location and the local terrain.

Storyline: With Hunter in danger, time is running out. It's time to start designing bio-armor that will withstand the extreme weather in the Survivorama. Thanks to Hunter's notes and your students' efforts, they now have the engineering design cycle to get them started. And Monet has more help to offer: secret documents hacked from Lisa's database that show what it really takes to survive in the dome (see Figure 2).

Figure 2: Terrain Report from the Desert Zone of the Survivorama

Develop

Students next apply what they have learned about the develop phase of the design cycle to research the problem, design a solution and create a prototype. Resources include a Materials Toolbox, bio-armor template, and prototype sketching software.

Storyline: With students' help in the DEFINE phase of the engineering design cycle, Monet now knows what hazards the bio-armor will have to withstand and what our design criteria are in each zone. What's next? Monet found another classified document that has information students can use to design the bio-armor (see Figure 3).

MATERIAL	PROPERTIES					
	FLEXIBLE	LIGHTWEIGHT	WATERPROOF	Resists HEAT	Resists CHEMICALS	Resists ELECTRICAL CURRENTS
Aerographite	●	●●●	●	X	●	X
Aluminum	●	○	●	X	●	X
Dyneema	●	○	●	○	●	●
Glass Fiber	●	●	●	○	X	●
Graphene	○	○	●	X	●	X
Kevlar	○	○	●	●	●	●
Metallic Glass	○	○	●	X	●	X
Microlattice	●	●●●	●	●	●	X
Nanocellulose	●	○	○	X	●	X
Nylon	●	○	●	X	●	●
Polycarbonate	●	○	●	●	●	●
Rubber	●●●	○	●	X	○	●
Spider Silk	●	○	●	○	○	●
Stainless Steel	○	X	●	●	●	X
Titanium	○	X	●	●	●	●

● = good at this ○ = okay at this X = bad at this

Figure 3: Material Property Document Discovered by Monet

Optimize

Students next apply what they have learned about the optimize phase of the design cycle to test their design, get feedback, and communicate their solution. Resources include a material cost table and the bio-armor template.

Storyline: Monet is growing desperate to rescue Hunter, before it's too late. The bio-armor designs for each zone are ready. But before building the bio-armor, Monet discovers that she has another constraint – she won't be able to access all the materials because some are too expensive for her to get. With new information about material costs, she'll need students to update and OPTIMIZE their designs to lower the bio-armor cost as much as possible.

Monet's Story Ends

A video wraps up Monet's story and provides a transition out of the world of the Survivorama.

Storyline: Using students' designs, Monet has built the bio-armor that can navigate the three zones in the Survivorama – and she's ready to rescue Hunter.

The Boston Molasses Disaster

In this section students take a deeper look at the engineering design cycle by investigating an engineering failure. Students solve the mystery of what went wrong–and why–by hunting through videos, animations, diagrams, real-life accounts, and historical photos and court transcripts (see Figure 4).

> Storyline: Students experience the strange-but-true story of the 1919 Boston Molasses Disaster through the eyes of real-life hero Isaac Gonzales, an immigrant who worked for USIA, the company in charge of the tank. Isaac risked being fired and even jailed as he repeatedly warned the company about the tank's imminent collapse. In this story a gigantic tank holding over two million gallons of molasses burst and flooded the streets of Boston's North End – with disastrous consequences. An entire neighborhood was destroyed and 21 people died. The collapse was the result of a series of failures in the engineering design cycle: the construction was rushed, the materials used to build the tank weren't strong enough, the tank was never tested, and warnings about leaks were ignored.

Figure 4: Control Panel for the Boston Molasses Disaster

Cellphone Holder Design Challenge

This challenge pulls together everything students have learned as they define, develop and optimize their own cellphone holder design.

> Storyline: Teachers and students in our state are worried about how kids use cellphones instead of paying attention in class. They've tried everything they can think of to stop the problem, and nothing is working. But they heard about a new idea: instead of trying to keep cellphones out of the classroom, use them to help learning. It turns out that in almost every subject, there's a good way to use cellphones for learning. Our school is going to be the first to use cellphones this way in sixth-grade classrooms. The cellphones on your desks have to be easy to

read and have to stay in place. There's one problem: our design also has to be low cost. One teacher suggested making cellphone holders out of cardboard. So this is our design challenge: can we design a cellphone holder that's made from cardboard?

Return to Earth Lesson

Return to Earth accompanies the "Earth's Place in the Universe" science unit. This two-day lesson introduces students to concepts of engineering design through the story of the disastrous Apollo 13 mission of 1972. It was created in collaboration with real-life hero, Francis (Poppy) Northcutt—the first female engineer to work in NASA's mission control. Return to Earth aligns with the Next Generation Science Standards (NGSS) for MS-ETS1 Engineering Design.

Storyline: The lesson opens with a first-person account from Northcutt, recalling her work at NASA's Mission Control. Students delve into the astronauts' plight when an oxygen tank on the Apollo 13 spacecraft explodes. With days to go before Apollo 13 can get back to Earth, carbon dioxide from the astronaut's own breath builds to nearly fatal levels. Like the NASA engineers of 1972, students gather supplies to design a filter fix that will lower the carbon dioxide levels and keep the astronauts alive.

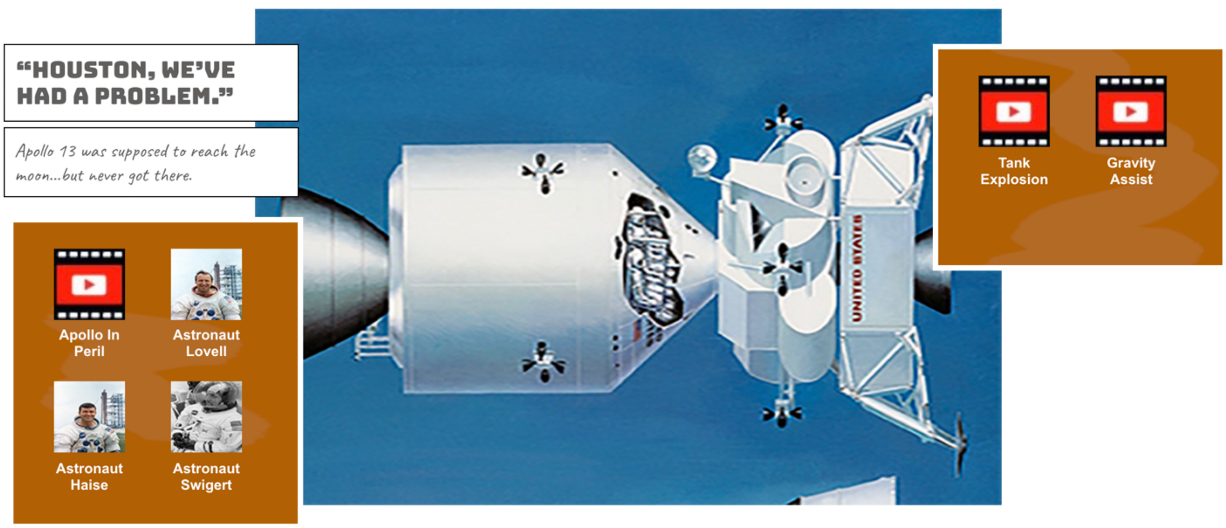

Figure 5: First Control Panel for the Return to Earth Lesson

Tragedy in Haiti Lesson

Tragedy in Haiti accompanies the "Earth's Systems" science unit. This one-day lesson reinforces the Define phase of the engineering design cycle through the story of the 2010 Haiti earthquake. Tragedy in Haiti aligns with the Next Generation Science Standards (NGSS) for MS-ETS1 Engineering Design.

Storyline: The lesson opens with a video account from 17-year-old Rachel Lunique, a real-life survivor of the quake. After hearing her story, students dig deeper into what happened on the day of the earthquake and its disastrous consequences: 300,000 people lost their lives and over a million were left homeless. Fictionalized case studies of four quake survivors highlight the desperate situation of the Haitian people. In the Design Challenge, students take on the role of engineers to identify the survivors' needs (criteria) and what stands in the way of getting aid to them (constraints).

Figure 6: First Control Panel for the Tragedy in Haiti Lesson

From the Future Lesson

From the Future accompanies the "Biological Evolution" science unit. It aligns with the Next Generation Science Standards (NGSS) for MS-ETS1 Engineering Design.

Storyline: This one-day lesson reinforces the engineering design cycle – Define, Develop, Optimize – through the story of Alejandra, a 14-year-old from far in the future. During a class field trip, Alejandra discovers "fossils" that are actually phones from different times in history, up to the smartphone of our day. With Alejandra, students see how phone designs have evolved, or improved, over time – and how technological evolution is the same and different from biological evolution. In the design challenge, students take the next step in the evolution of phone design: designing an app to help fifth-graders making the transition to sixth grade.

Figure 7: First Control Panel for the From the Future Lesson

IV. Teacher Website (http://teemsproject.com)

A teacher website supports teachers and schools implementing the TEEMS curriculum. The most important resources on the site are guides for each unit and lesson. Each guide includes:

- A description telling the story of the unit or lesson, the time needed to complete it and the NGSS standards addressed;
- A list of materials needed for classroom implementation;
- Documents to be printed out for students;
- Diagrams showing the flow of the lesson (for example, see Figure 1);
- Step-by-step instructions for implementing each unit or lesson with discussion prompts, guidance for using resources on the student learning website, links to additional resources and tips for teachers.

Another import resource on the site is a set of instructional videos for teachers. Example topics include insights on the engineering design cycle and why students should learn about the design cycle.

V. Context of Pilot-Year Implementation and Outcome Assessments

The TEEMS curriculum is currently being piloted in the Springfield Public School (SPS) system, an urban public K-12 school district in a northeastern state. The district serves more than 25,000 students from preschool to grade twelve in 32 elementary schools, 12 middle schools, 3 schools serving grades 6 to 12, and 8 alternative schools. The district also includes magnet schools, vocational schools, and a variety of other specialized educational settings. Most students in the district are Hispanic (67%) or African American (19%). A vast majority (83%) of the district's students are considered "high needs," which is a designation that includes factors related to language needs, economic disadvantages, and/or disability status.

Six of the district's 12 middle schools have agreed to participate in the TEEMS pilot; 4 are being used as treatment schools and 2 as comparison (non-treatment) schools. Each of the schools has a single 6th grade science teacher. There are 724 students participating in the pilot year, 410 in treatment classrooms and 314 in comparison classrooms.

Following the pilot year, the TEEMS curriculum will be revised based on formative assessment data collected in the pilot year. Then the full TEEMS curriculum (two units and six lessons) will be tested for two years throughout participating SPS schools. Data will be collected using a mixed methods approach to measure both learning and the development of STEM identity.

VI. Assessing the Effectiveness of Cognitive Tools via Preparation for Future Learning

A significant goal of exploring the effectiveness of a curriculum based on IE theory is to gather evidence concerning the efficacy of employing IE cognitive tools as a means of facilitating student learning. This was expressed most clearly in a recent round-table webinar[29] wherein researchers at the Center for Imagination in Research, Culture, and Education (CIRCE), including Kieran Egan and Gillian Judson, highlighted that assessment of IE-embedded student learning should depend on the effect of cognitive tools as a central construct of investigation.

Our present efforts at capturing indicators of the effectiveness of cognitive tools were primarily informed by our understanding of the capacity of cognitive tools to serve as exemplars of strategic mediation of student learning[30] and an understanding based on Egan's own articulation of the role of cognitive tools as mediators.[31] Also informing our efforts are associated theoretical works in the field of IE development like those of Fettes[32] which draw a parallel between IE cognitive tools and the "psychological tools" expressed in sociocultural theory, the role of which was to serve as support for mediation.

Seeking to carry out a fine-grained assessment of the effect of cognitive tools as mediators, we made use of a variant model of transfer of learning[33] known as *preparation for future learning* (PFL). In this model transfer is re-contextualized and bifurcated into the constructs of *transfer-in* learning, describing innovation-oriented learning that emphasizes interpretive knowledge, and *transfer-out* learning, characterized by efficiency-oriented learning and a dependence on replicative and applicative knowledge.[34,35] In later work applying the PFL assessment model to sociocultural theory, Bransford, Sears, and Chang[36] demonstrated a method by which PFL could account for incremental elements of successful mediation, identifying the characteristics of *transfer-in* learning as indicators of proximal navigation along the trajectory of learning development and the characteristics of *transfer-out* learning constituting indicators of distil development through which learning is crystallized into independent performance.

Because *transfer-in* learning is not commonly assessed as a traditional outcome of instruction,[34] our early, pilot year efforts to assess student learning have centered on creating an assessment instrument that could–at sufficient levels of reliability, credibility, and rigor–capture indicators of *transfer-in* learning. The structure of our pilot assessment items were, in part, derived from exemplar categories of PFL student behavior and expressions of *transfer-in* thinking,[36] as well as those represented in established assessment strategies reflected in extant PFL assessment instruments, especially in prior research projects like those of Arena[37] and Grover, Pea, and Cooper.[38] However, when appropriate, we also remained open to incorporating new categories of interpretation grounded in evidence based on student response patterns to PFL prompts.

VII. Development and Implementation of a PFL Assessment Instrument

Our initial effort at designing a PFL assessment produced an instrument focusing in a broad, exploratory manner on capturing both *direct* and *indirect* indicators of *transfer-in* learning. Questions 1A and 1B were organized as constructed response questions referencing a narratively-framed, multi-stage problem-solving scenario (question 1A is illustrated in Figure 8). Questions 2 and 3 were intended to gather evidence of students' ability to reflect on their experiences learning engineering concepts. Finally, questions 4 and 5 targeted specific levels of students' engineering knowledge (following Broudy[39]): question 5 was a scenario-based selected response item intended to measure students' replicative knowledge of engineering concepts and the question 6 was an interpretive drawing task.

Stakeholder participation in the development of the student learning outcome assessment was a high priority in this project. As such, several rounds of expert revision–provided by professionals both internal and external to the project–guided the creation of this instrument. The earliest draft, based on ideas for a dynamic assessment of PFL was composed in February of 2019. This was modified for conceptual clarity and was expanded in scope as a result of collaboration with partners at STCC and CIRCE. A draft was then submitted to the SPS Design Team – a focus group of middle school teacher-leaders from the participating school district – who suggested improvements to language use and accessibility. A fourth round of revisions was implemented, following the advice of collaborators specializing in assessment and evaluation, focusing on the structure of the prompts. Finally, after compiling this feedback from multiple sources, a working draft of the six-item pilot instrument was composed for use in September of 2019.

1a. Some of your neighbors (people who live near you) have worked hard to raise money and buy some empty land on Springfield Avenue. Now they want to make it into something better. How can *you* help? You're a middle-school student who knows about engineering design – so you can give your neighbors ideas about how to solve their problem.

Thinking like an engineer, what would you say to your neighbors about their first step in figuring out how to use the land?

Figure 8: PFL assessment question 1A

VIII. Key Findings from Early Analysis of Student Learning Outcome Data

As of January 2020, the first 243 student responses, roughly 33% of the expected total, have been collected and analyzed, representing assessment results from two treatment condition classrooms and one comparison class. These pilot data have been sufficient to inform useful interpretations, providing a basis for drawing conclusions about the effectiveness of our assessment items and framing tentative propositions about the potential role of a curriculum based on cognitive tools in facilitating preparation for student learning.

Based on the quality of responses to items in the assessment instrument, we decided during the earliest phase of analysis to exclude questions 1B, 2, 3 and 4 and retain questions 1A and 5 for further evaluation. In some cases, this decision owed to recognizing the highly experimental nature of the question (as with 1B and 4) which appears to have created unclear establishing conditions for students, resulting in little variability in student responses. In other cases, as with questions 2 and 3, the reflective quality of the prompt seemed to have proved too variable, resulting in a dispersive overabundance of response categories that could not be further reconciled.

Evaluation of responses to questions 1A and 5 each then proceeded from the generation of a rubric by which scores could be assigned. For question 1A, rubric categories were largely *a priori* adaptations of PFL behaviors exemplified in the literature,[35,37] these being categories structured primarily to reference indicators of (1) strategizing, (2) collaboration and (3) resource-seeking, and indications of partial orientation to those behaviors in the engineering context—such as (4) measuring, (5) modelling, and (6) considering impacts; these were organized into a four-point ordinal scale ranging from negligible to advanced *transfer-in* thinking (see Figure 9).

For question 5, rubric categories were partially based on PFL behaviors, most especially those related to displays of interpretive knowledge,[35,39] but were also informed by patterns of student responses identified in comparisons of student work; in this way, five nominal categories were established, grouping student's responses as demonstrating: (1) poor orientation, (2) an unelaborated schematic, (3) an elaborated schematic, (4) a rote engineering design process, or (5) an interpreted engineering design process.

Comparative statistical analysis of student responses to questions 1A and 5 has provided promising evidence of the effectiveness of instruction guided by cognitive tools to positively influence preparation for future learning. For question 1A, a non-parametric analysis was conducted on early by-group data. An independent two-group Mann-Whitney test was conducted to investigate differences among the treatment (n = 157) and comparison (n = 88) conditions. This analysis indicated that the PFL thinking variable was significantly greater, in the statistical sense, for the treatment group (Mdn = 3) than for the comparison group (Mdn = 2), U = 5051.5, p = .0002941. This analysis supported the inference that there was a significantly greater tendency to engage in PFL thinking among students in the treatment group. One clear corollary of this inference could be found in the percentage of students in each condition who could produce at least one indicator of PFL thinking in their response: In the treatment condition, 59.9% of students responded with at least one statement indicating PFL thinking, whereas in the comparison group only 37.4% of students responded in this manner.

Question 1A Rubric			
1 (Negligible Thinking)	**2 (Emerging Thinking)**	**3 (Basic Thinking)**	**4 (Advanced Thinking)**
Student's response contains **no items** from the **basic/advanced design thinking** or the **emerging design thinking** lists, instead exemplifying **taking immediate action, resisting collaboration** or **disengagement**. **Examples from Student Responses:** • **Taking immediate action:** "build a park", "build a house", "fix the land up", "plant some new trees", "cut the grass" • **Resisting collaboration:** "tell them to do", "give them ideas", "tell them what I want" • **Disengagement:** "I don't care", "I don't know this"	Student's response contains **no items** from the **basic/advanced thinking** list, and contains one example of **measuring, modelling,** or **considering impacts.** **Examples from Student Responses:** • **Measuring:** "find the area of the land", "measure the land", "figure out the budget", "get your materials" • **Modelling:** "make a prototype", "draw a blueprint", "make a sketch", "come up with a model • **Considering impacts:** "think of the benefits", "think of impacts", "ask about side-effects"	Student's response contains one example of **strategizing, collaborating**, or **seeking advice**: **Examples from Student Responses:** • **Strategizing:** "find the problem", "define the problem", "make a plan", "think a solution", "set a goal" • **Collaborating:** "ask for my neighbors for ideas", "see what problems they have with this land", "ask 'what do want to do?'", "share ideas with neighbors", "vote on an idea" • **Seeking advice:** "talk with experts", "talk with people who know", "do research", "gather info from others", "buy a book", "study the problem"	Student's response states and then elaborates or restates their thinking, containing **two or more** examples, in any combination, of **strategizing, collaborating**, or **seeking advice**: **Examples from Student Responses:** • **Strategizing:** "find the problem", "define the problem", "make a plan", "think a solution", "set a goal" • **Collaborating:** "ask for my neighbors for ideas", "see what problems they have with this land", "ask 'what do want to do?'", "share ideas with neighbors", "vote on an idea" • **Seeking advice:** "talk with experts", "talk with people who know", "do research", "gather info from others", "buy a book", "study the problem"

Figure 9 Question 1A scoring rubric

For Question 5 a chi-square test of independence was carried out to examine the relationship between condition (treatment vs comparison, with the same sample sizes as above) and category of responses based on the rubric, which provided a proxy indicator of students' interpretive knowledge of the engineering design process. The relationship between these variables was found to be significant, X^2 $(4, N = 245) = 36.33$, $p < .001$. This finding supported the inference that student responses incorporating the production of a certain type of diagram displayed a statistically significant tendency to depend on whether the student was in the treatment group or the comparison group. In context, it is worth noting that the most theoretically "correct" response, producing a highly-interpreted and sophisticated diagram, was demonstrated in the treatment group far more often – at a ratio of more than 4:1 against the comparison group.

IX. Discussion

Formative assessment has been critical in providing direction for developing the TEEMS learning environment in a way that best meets the needs of teachers. For example, in developing IE-based learning environments over the past five years we have noted the need for software that is robust on a wide variety of platforms (including those that may be outdated or that have only minimal support); that requires little engineering expertise in supervising and supporting its use; and that is adaptable to a variety of teacher needs and time schedules.[40]

In developing the TEEMS curriculum, we are continuing to listen to teacher concerns and adjust the curriculum accordingly. In focus groups with teachers conducted by an external evaluator, the evaluator reported that "The TEEMS curriculum is well-received by teachers, engaging for students, and may influence teaching of other units." She also noted the following:

- Treatment teachers were overwhelmingly positive about and appreciative of the curriculum, which, with the exception of some moments of confusion, was reported to be easy to follow and use.
- Teachers used words like *hands-on, problem solving, creativity, and active engagement* to describe how the curriculum was different from other science units.
- They broadly agreed that their students displayed higher-than-usual enthusiasm for the TEEMS units and lessons, with one teacher noting, "Students were so engaged; it was exciting to see students that would say, 'this is so boring' be totally engaged.

In addition, the evaluator reported three key ways that the curriculum had felt like a valuable experience for them and/or their students:

- *Appreciation of the value of story in teaching science content*.
  Key quote: "[In another unit] there is an end-product about discovering a new planet, but there is no story behind it. [In the future I might] try to create a story and add videos of real-life work on other planets."

- *A new understanding of how to teach the skills of collaboration/teamwork* (especially through the use of the videos and watching real teams work).
  Key quote: "[A student presented his cell phone idea to the class] and he credited another student; it led to discussion of sharing ideas and crediting."

- *Realization of the importance of the teacher's role in helping students think divergently*, rather than immediately narrowing to a right answer.
  Key quote: "I learned that I have to be more open-minded about how I respond to students so that I'm not stifling their thinking…[so they see] there is not one right way."

Pilot-year results from the preparation for future learning (PFL) assessment instrument have provided encouraging early evidence to support the assertion that IE cognitive tools, in their role as mediators,[18,31,32] can facilitate student learning by providing a scaffold for immature conceptual knowledge in such a way as to allow students to more successfully orient themselves to new learning contexts[35-37]. When posed a novel problem-solving scenario task, as in question 1A of the PFL assessment, students in the treatment group responded, to a degree greater than those in our non-treatment classrooms, with statements that showed their capacity to orient to the problem through *transfer-in* thinking. Similarly, as was indicated in the pattern of early responses to question 5 of the PFL assessment, when called-upon to create a pictorial representation of their understanding of the engineering design process – the conceptual focus of the engineering unit – students in treatment classrooms were able to demonstrate a greater capacity to "think with" the concept in an interpretive manner, producing a greater number of sophisticated examples of the engineering design process.

In the years to come, our intention is to expand our repertoire of approaches to PFL assessment in the context of measuring the effectiveness of a curriculum based on transnarratively-guided Imaginative Education, creating conditions to elicit measures of transfer of learning that integrate more fully into the transmedia framework by which the curriculum as a whole is composed. The discrete nature of PFL assessment as it has occurred in the pilot year has proved to be a limitation to articulating an ideal, dynamic assessment scenario for measuring PFL – whereby students are offered incremental opportunities to demonstrate their ability to learn from new materials as they are presented[34, 35] – and, going forward, we would like to ameliorate the circumstance by incorporating assessment items into classroom activities.

X. Conclusions

We have applied the theory of Imaginative Education to develop an engineering learning environment that is based on the Next Generation Science Standards. While currently half finished, when completed it will consist of two multi-week engineering design units and six shorter lessons that apply engineering design to various science topics taught in the sixth grade. The curricula is currently being piloted in sixth-grade classrooms to research its impact for increasing (1) learners' capacities to engage in both innovative and direct application of engineering concepts, and (2) the formation of STEM identity.

Early results from the PFL assessment have provided data to support that students in treatment classrooms can display greater indication, both indirect and direct, of PFL. Our item by which we evaluated indirect indication of PFL, students' ability to display *transfer-in* thinking demonstrated a pattern of response which contained a greater degree of PFL thinking behaviors as a result of IE-based instruction. A similar pattern favoring a tendency for greater PFL thinking among students in treatment classrooms was determined with respect to responses to our direct PFL assessment item – through which we attempted to measure students' interpretive knowledge. On the whole, these early data have helped to advance the notion that IE cognitive tools can successfully serve as mediators of student learning by providing a framework by which students can orient themselves to take advantage of new learning.

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