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Designing a Multimedia Learning Environment that Engages Children Through Narrative

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Glenn Ellis is a Professor of Engineering at Smith College who teaches courses in engineering science and methods for teaching science and engineering. He received a B.S. in Civil Engineering from Lehigh University and an M.A. and Ph.D. in Civil Engineering and Operations Research from Princeton University. The winner of numerous teaching and research awards, Dr. Ellis received the 2007 U.S. Professor of the Year Award for Baccalaureate Colleges from the Carnegie Foundation for the Advancement of Teaching and the Council for Advancement and Support of Education. His research focuses on creating K-16 learning environments that support the growth of learners' imaginations and their capacity for engaging in collaborative knowledge work.

Mr. Al Rudnitsky, Smith College

Al Rudnitsky teaches Introduction to the Learning Sciences; Thinking, Knowing and the Design of Learning Environments, How Do We Know What Students are Learning?; and instructional methods in elementary and middle school mathematics and science. He has authored books on curriculum design and teaching children about scientific inquiry. Current research interests focus on creating environments for "good talk" in elementary and middle school classrooms, and also on advancing the use of knowledge building pedagogy in higher education. His most recent article (2013) is entitled "Tasks and Talk: The Relationship Between Teachers' Goals and Student Discourse," in Social Studies Research and Practice.

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Beth McGinnis-Cavanaugh, M.S. Civil Engineering, University of Massachusetts Amherst, is professor of physics and civil engineering technology at Springfield Technical Community College. She focuses on developing meaningful educational strategies to recruit and retain a diverse student body in engineering and designs innovative learning environments at all levels of the engineering pipeline. With expertise in the design of PD and learning communities, Beth leads a collaboration with educators as co-PI on an NSF K12 engineering education project. She is the 2014 Carnegie Foundation for the Advancement of Teaching and the Council for Advancement and Support of Education Massachusetts Professor of the Year.

Ms. Isabel Huff, Springfield Technical Community College

After participating in the instructional design of Through My Window during her four years as an undergraduate, Isabel is thrilled to be working full-time as the outreach coordinator. She graduated summa cum laude from Smith College with a double major in Economics and Spanish in Spring 2014 and now works on the Springfield Technical Community College side of the Through My Window National Science Foundation grant.

Ms. Sonia K Ellis, Smith College

Sonia K. Ellis holds a B.S. in chemical engineering from the University of Pennsylvania and an M.S in chemical engineering from Princeton University. She is a fiction writer and instructional designer. On the Through My Window project, she is the author of Talk to Me, with a second young-adult novel in progress, and a designer and editor of the online learning adventures.

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Designing a Multimedia Learning Environment that Engages Children Through Narrative

I. Abstract

This paper examines the use of Imaginative Education for designing an online learning environment for middle school engineering education. In Imaginative Education, cognitive tools associated with the development of linguistic ability are used to engage learners and frame their learning productively. The *Through My Window* website applies a variety of cognitive tools related to mythic and romantic understanding through the use of an online novel and interactive learning adventures associated with the novel. The focus of this paper is an AI learning adventure on the website titled Rio's Brain. It was found, through embedded assessment within the learning adventure, that learner's ideas advanced during the adventure. It was also found that the adventure supported the development of interpretive knowledge and created a Zone of Proximal Development (ZPD) wide enough to support a range of learners.

II. Introduction

Our society is dependent on engineering and technological advances for its prosperity. It is also becoming increasingly recognized that to make informed choices and understand our world, *all* citizens need to have at least a basic understanding of the processes and uses of engineering.[1] The result is that engineering is becoming a bigger part of both formal and informal K-12 education. In a review of K-12 engineering education in the United States, the National Academy of Engineering and the National Research Council report that the potential benefits of introducing children to engineering can be grouped into five areas:

- 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]

They also note that the impact in science and mathematics may be particularly significant for underrepresented minorities. Finally, they indicate a belief that "engineering education may even act as a catalyst for a more interconnected and effective K–12 STEM education system in the United States." [2]

This paper reports on the development of an online learning environment called Through My Window (available at www.throughmywindow.org). Through My Window introduces middle school age children to engineering through the use of narrative. The website currently consists of the following:

- *Talk to Me* illustrated novel with eReader
- *Talk to Me* audiobook with optional subtitles

- Rio's Brain Learning Adventure

Additional learning adventures about engineering design and engineering ethics will be added to the website in 2015. A second novel with associated learning adventures is also in development for 2015-2016. Although the *Talk to Me* novel is available for free on the website, some educators indicated a preference for a traditional print version of the book, which is now available.[3] Finally, significant support for teachers and parents is available through an associated website, Team Through My Window (available at www.teamthroughmywindow.org). This website includes information and a variety of tools for supporting educators using Through My Window. Of particular importance are video tutorials for using the website and a teacher's guide for enhancing learning. The teacher's guide includes a variety of support materials for implementing Through My Window including: chapter summaries, vocabulary words, writing prompts and activities linked to chapters in the *Talk to Me* novel; activities linked to the Rio's Brain learning adventure; and pathways for integrating the online and offline curricula.

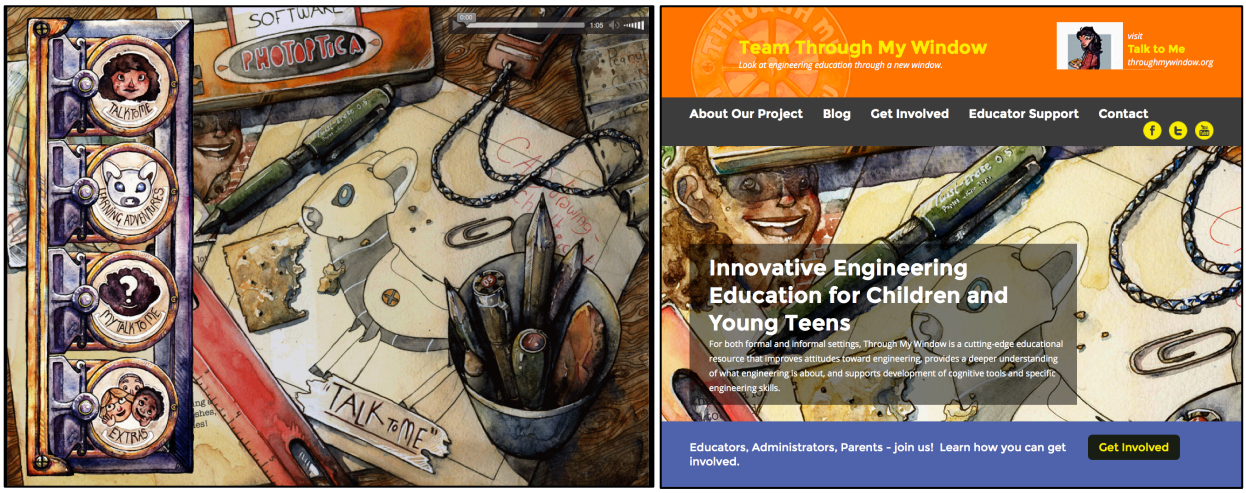

Figure 1: The Through My Window homepage (left) shows options for reading the *Talk to Me* novel, engaging in learning adventures and other options. The Team Through My Window homepage (right) shows options for learning about the project and accessing educator resources.

III. Imaginative Education

> Engaging the imagination is not a sugar-coated adjunct to learning; it is the very heart of learning. It is what brings meaning and sense and context and understanding to the knowledge we wish to teach.
>
> --Kieran Egan, *An Imaginative Approach to Teaching*[4]

The learning sciences place great emphasis on developing learning environments that support deep understanding.[5,6] Central to deep understanding is determining whether knowledge is usable, transferable, can be employed to advance one's knowledge, and can be used in the creation of new knowledge. The publication of *How People Learn* in 2000 indicated the need for new approaches to teaching traditional subjects, with the goal of making it possible "for a

majority of individuals to develop a deep understanding of important subject matter."[5] One approach cited in *How People Learn* is Imaginative Education (IE) developed by Kieran Egan.

Imaginative Education builds on learners' characteristic ways of thinking to structure their engagement with ideas and knowledge.[4,7,8] The intent is to engage learners' imaginations in their pursuit of understanding and thus engender the kind of caring about learning necessary for developing deep understanding. In the IE approach, instruction is designed to support a developmental sequence of five different stages of understanding that enable learners to make sense of the world in different ways. Learners progress to new stages by mastering the cognitive tools associated with each stage of understanding. (Cognitive tools are mental devices developed by our ancestors to help make sense of the world and to operate more effectively in it.)

The most important cognitive tool is narrative. Egan writes, "Narrative understanding is a tool related to our ability to best make sense of things when we can grasp their emotional impact. A narrative context for knowledge can establish its emotional importance while also conveying the knowledge—about physics or mathematics no less than about history or literature." [4] 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?' They experience events through the protagonists…" [9] Thus a well-crafted story is a cognitive tool that can convey a coherent view of understanding in a memorable form while at the same time helping the learner engage emotionally with the information being communicated. 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 learners.[10] They are the primary means learners have of relating their existing knowledge to the new ideas they are learning[11] and to express their understanding of the world.[12] They ground complicated concepts in concrete terms and connect abstract ideas with emotions and events.[13]

According to IE theory, the narrative structures most appropriate for middle school age children build on two of the five types of understanding described by Egan: mythic understanding and romantic understanding. Mythic understanding begins as learners develop enough linguistic ability to discuss and understand things they haven't physically experienced. They have a desire to arrange their worlds and do so with binary contrasts like hot/cold. At this age learners also become aware of a sense of mystery that surrounds our knowledge and they are comfortable in a world containing myth and fantasy. Romantic understanding begins as learners see the world more realistically. An interest in binary contrasts becomes a fascination with the limits and extremes of reality, since romantic learners are trying to find the edges of the world they are beginning to comprehend. Romantic learners are also interested in heroes and how they face the challenges of reality.[4] The mystery, fantasy, extremes of reality and heroic narratives woven throughout Through My Window are examples of cognitive tools associated with mythic and romantic understanding.

IV. Through My Window Website

Still in its early stages of development, the Through My Window website currently has two major elements. These are the *Talk to Me* novel and Rio's Brain learning adventure. This paper focuses mainly on the learning adventure.

Talk to Me Novel

The *Talk to Me* novel is presented in the form of an eReader on the Through My Window website (see Fig. 2). The novel tells the story of fourteen-year-old Sadina Reyes. Sadina is the sister and protector of Maddie, who can talk only to her family and Bella, her robotic cat. But with the rest of the world, Maddie is too terrified to speak a word. Maddie wakes one night to find an intruder in the house, and now she's the only one who can identify him and save Mom from being arrested. Sadina suspects her best friend, Rio — especially now that Rio has started paying attention to another girl. With Mom in trouble and Rio acting like a stranger, Sadina's world is collapsing. And that's when her friends join together to help transform Bella into Chattercat, a talking robot that just might get some answers from Maddie. In using the engineering design process to build the cat and solve the mystery, Sadina and her friends learn about artificial intelligence and collaborative innovation. They are also involved in ethical dilemmas paralleling the kinds of situations that professional engineers and technologically literate citizens might face.

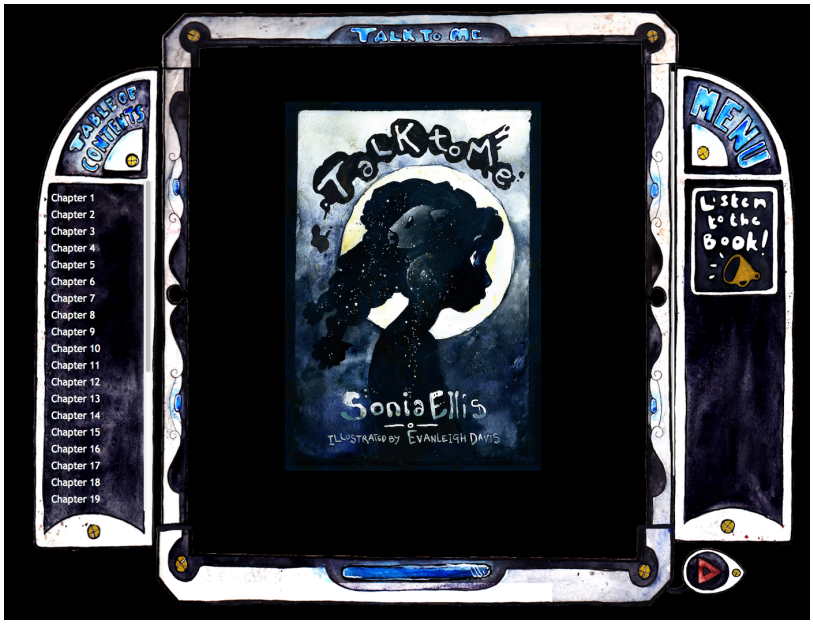

Figure 2: *Talk to Me* eReader on the Through My Window website. The novel is illustrated throughout and the eReader includes an audiobook with subtitles.

The novel introduces learners to engineering design, artificial intelligence and the ethical decisions that are inherent in using technology. It shows that engineering is not just about technology, but also about helping people. Finally, *Talk to Me* gives teachers the opportunity to encourage technological literacy across disciplines—such as language arts and science/technology classes. This is consistent with the approach championed by the International Technology and Engineering Educators Association (ITEEA). They write, "When taught effectively, technology is not simply one more field of study seeking admission to an already crowded curriculum…Instead, it reinforces and complements the material that students learn in other classes." [1]

Rio's Brain Learning Adventure

The first learning adventure available on Through My Window is Rio's Brain. In this adventure users explore a mysterious mansion in which they learn about the nature of intelligence, artificial intelligence, Alan Turing, the Turing Test and natural language processing. Requiring about three hours to complete, the adventure is stand-alone and doesn't require learners to have read the *Talk to Me* novel. However, by reading the novel first, learners are introduced to the characters and ideas that they will encounter in the adventure. Not only will they see the characters again in the learning adventure, but now they will have a chance to interact with them.

Consistent with IE theory, a key feature of the learning adventure is that all the tasks, questions, and writing prompts are integrated into the storyline. As a participant in this mysterious world, users are motivated to learn and engage with new ideas because they are needed to save Rio. At the end of the adventure learners must make a decision: Can an artificial brain take the place of Rio's real human brain?

During the adventure, learners are given the opportunity to think about engineering, technology and intelligence in new ways. They see that engineers are involved in designing things that they might not ordinarily think of as "engineering," such as designing intelligent machines.

Graphic Novel Introduction

Learners begin the adventure by reading an online graphic novel with sound effects. The graphic novel is inspired by Daniel Dennett's famous story, "Where am I?" that challenges our ideas about the nature of consciousness.[14] Sample screenshots from the graphic novel are shown in Fig. 3 and a synopsis is provided below:

> While on a camping trip, Rio falls over a cliff and loses consciousness. He wakes up to find himself in a lab called SCARE—the Springfield Center for Acuity Research and Experimentation. The researchers have removed Rio's brain. They plan to run experiments on the brain and then destroy it. Rio, who is still receiving radio transmissions from his brain, manages to break out of SCARE and find Sadina. Together, the two of them decide to track down the mysterious Dr. Ecks, an engineer who does research on brains and artificial intelligence. But Dr. Ecks has disappeared, and her mansion has been ransacked. Can Rio and Sadina search the mansion and find the clues they need to get a new brain for Rio? The graphic novel ends when Sadina asks the learner to take over the adventure and explore the mansion because she must stay with Rio, who has collapsed.

The graphic novel sets the stage for the adventure in this imaginative world and then transfers agency over to the learner. In the mansion the learner explores three rooms to learn about ideas that will eventually help Rio.

Dr. Ecks' Mansion—Room 1

The focus of the first room is expanding the learner's ideas about the nature of intelligence. For example, learners encounter scattered notes from Dr. Ecks' notebook where she has recorded her initial thoughts about what intelligence is. Learners sort these notes based upon how much they believe Dr. Ecks' ideas are like their own ideas (see Fig. 4). During the adventure they can

revise their choices as their ideas change. Intelligent feedback also challenges learners to reflect upon their choices.

Another important element of Room 1 is the use of videos to expand the learner's initial ideas. For example, learners watch three short videos showing amazing artists, musicians and various physical performers. They then record their ideas about whether there are different ways to be intelligent. In Room 1 (and at all times in the adventure) learners can access and revise their ideas as well as share and compare them with those of other learners (see Fig 5). They can also save videos and other important information.

Dr. Ecks' Mansion—Room 2

In Room 2 learners encounter examples of machine intelligence and begin to consider what it means for a machine to have knowledge, have ways of working with that knowledge and have ways of learning new knowledge. Learners again sort more of Dr. Ecks notes. In this case the notes are about actions that intelligence machines might be able to take; learners decide if they think these actions are easy, tough or very tough. Learners then watch short videos about amazing machines—for example a robotic table tennis player—and write about what the machine needs to know to perform each action (see Fig. 6). Additionally, in Room 2 the learners play two games (see Fig. 7). In one game, machines use feedback from the learner to guess the number that the learner is thinking of. The learner needs to figure out the algorithm used by each machine. In the other game, learners see the inner workings of the 20 Question game as it guesses what object the learner is thinking about.

Dr. Ecks' Mansion—Room 3

In Room 3 learners encounter the story of Alan Turing and are introduced to the Turing Test (a test of a machine's ability to pass as human). The key concept in this room is considering the knowledge a machine can have and its ability to operate on that knowledge. Consistent with IE theory, this room links a real heroic person to questions of great depth and importance. After learning about ideas related to natural language processing, learners "talk" to a chatterbot that has been custom animated and programmed for the adventure (see Fig. 8). Here they have the chance to try a wide variety of questions and see how an "intelligent" computer responds. Their challenge is to understand why questions that are easy for humans to answer can be difficult for machines to answer in a humanlike way (and vice versa)—which is important information for helping Rio get a new brain.

Learners should leave the adventure with a deeper understanding of the kinds of things that intelligent machines can do. They should also have an improved understanding of the problems engineers must solve to create a machine that thinks like a person. This adventure should expand learners' ideas about the nature of engineering, potentially leading to increased STEM identity by introducing them to new kinds of problems and problem solving. Finally, the heart of our e-pedagogy is to provide opportunities for learners to think about new questions or work with new information. An effective way to increase the likelihood of this kind of thinking is to have learners write about their ideas, which occurs throughout the Rio's Brain learning adventure.

Figure 3: Sample screenshots from the introductory graphic novel in the Rio's Brain learning adventure. They show Rio coming to Sadina's house for help; Rio telling the backstory of his camping trip; Rio telling about falling off a cliff; Rio in bed in the SCARE laboratory; Rio looking at his own brain in a vat; and Rio and Sadina looking through gates at the mysterious mansion of Dr. Ecks (at which point the learner takes over as the protagonist).

Figure 4: Screenshots of the online journal in Room 1 of the Rio's Brain learning adventure showing a prompt for sorting ideas (above) and a screen for viewing and re-sorting ideas (below).

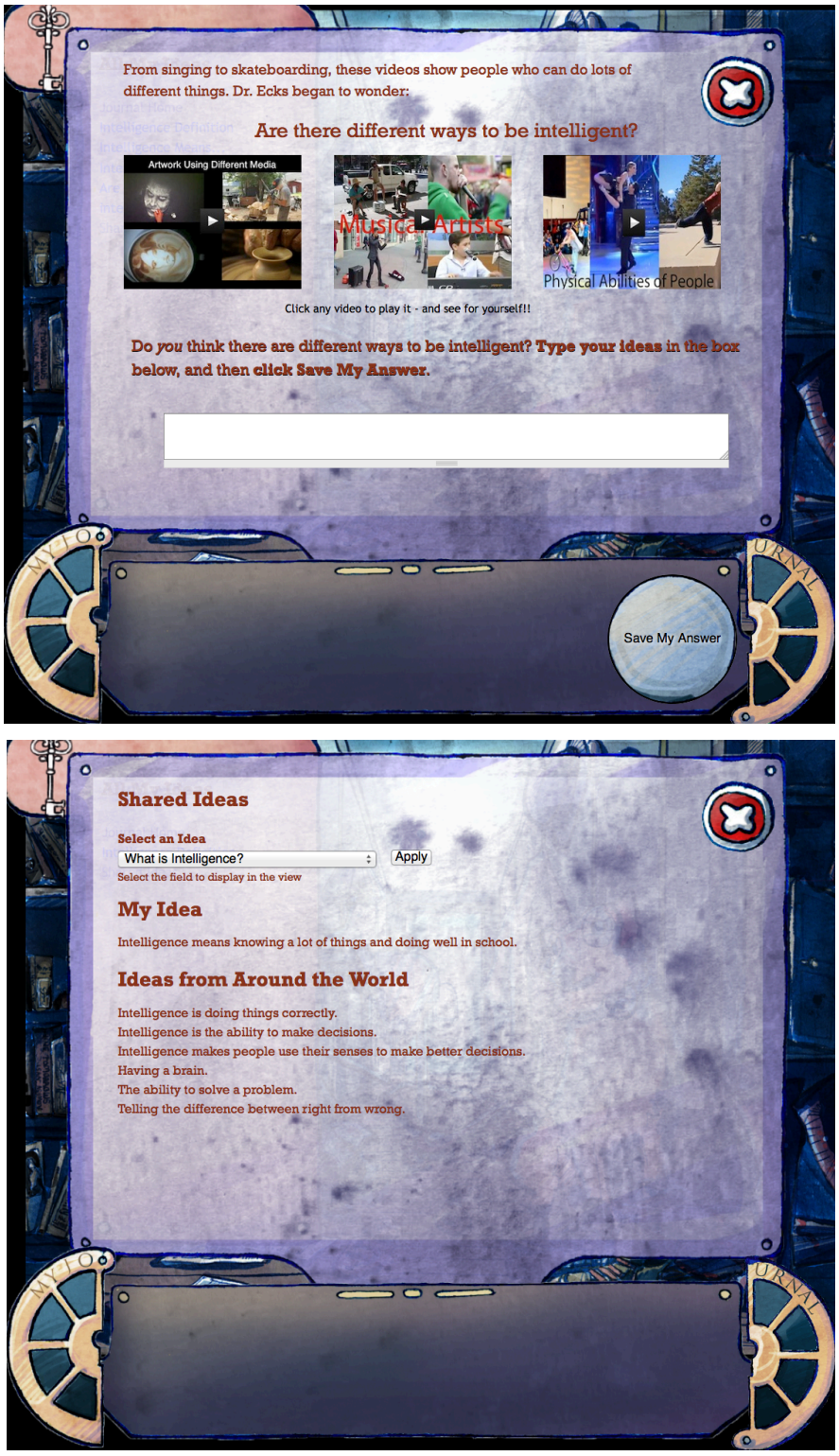

Figure 5: Screenshots of the online journal in Room 1 of the Rio's Brain learning adventure showing amazing examples of intelligence videos (above) and a journal page where learners can share their ideas with other learners (below).

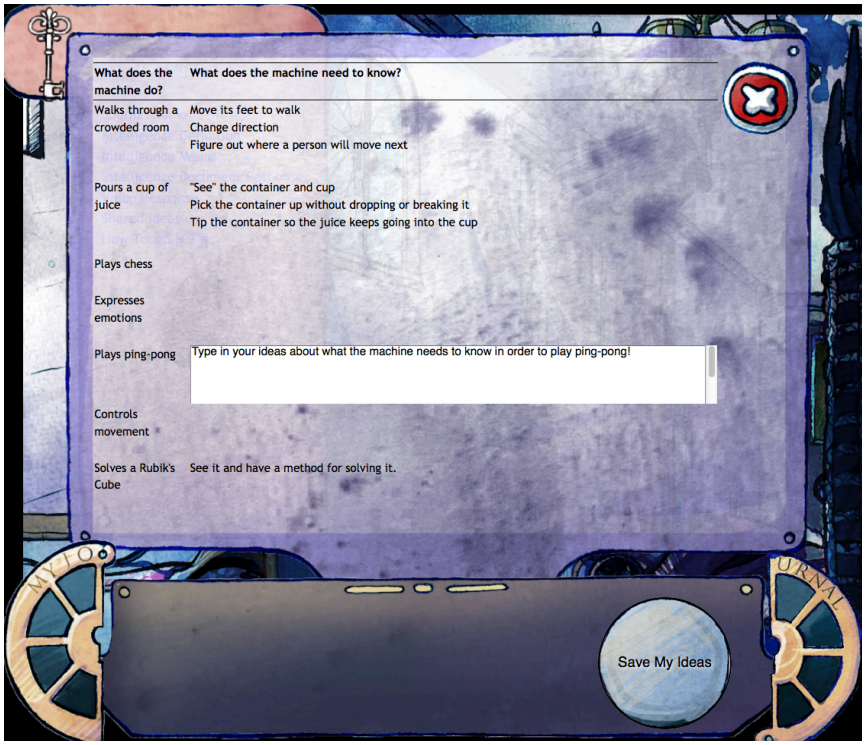

Figure 6: Screenshots of the online journal in Room 2 of the Rio's Brain learning adventure showing intelligent machine videos with Dr. Eck's notes (above) and prompts for journal entries related to the intelligent machine videos (below).

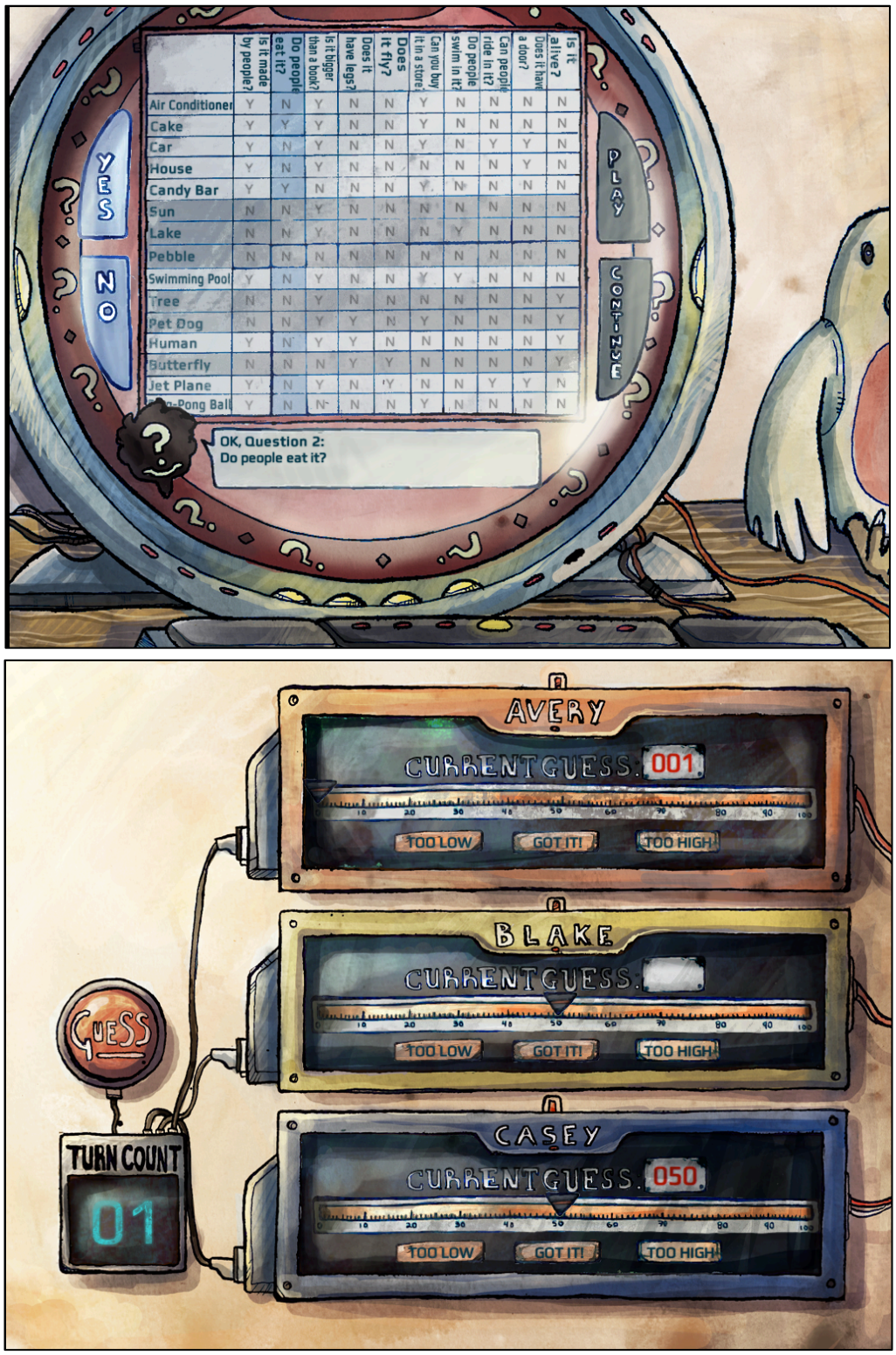

Figure 7: Screenshots of sample games from Room 2 of the Rio's Brain learning adventure showing a game for decoding and comparing algorithms for guessing numbers (above) and a game for exploring the inner workings of 20 Questions (below).

Figure 8: Screenshot from Room 3 in the Rio's Brain learning adventure showing the activity for conversing with a chatterbot that has been animated to match the storyline.

IV. Assessment

Assessing the effectiveness of the Through My Window learning environment means addressing several important questions:

1. Are students more likely to consider engineering and STEM as something they might be interested in?
2. Do students have a better understanding of the work of engineers?
3. Do students learn the big ideas about subjects such as engineering design, ethics and engineering, or artificial intelligence?

We are currently in the process of implementing a comprehensive assessment plan to investigate these three questions. In this paper, the focus is on question 3—what do students learn about artificial intelligence? Increasing students' identification with STEM and improving their understanding of the work of engineers (questions 1 & 2) depends on the success of the learning adventures. If students are not engaged in the learning adventures, it is unlikely that they will improve in these dimensions. Student data is only beginning to become available to address these two questions. The evidence of learning used here is based on data generated in the

Bellingham Memorial Middle School, MA. Over 150 students, the entire 8th grade, participated. The data source is students' responses to the various questions and tasks posed by the AI adventure. The analysis focuses on ideas embedded in student responses to questions in Rooms 1 and 2.

Room 1: Ideas about Intelligence

At the beginning of Room 1 in Rio's Brain learning adventure, students are asked to write their initial ideas about intelligence as part of the storyline. After completing Room 1 students then revise their initial ideas. Comparing these "before and after" sets of ideas about intelligence provides evidence of student thinking and idea growth. This qualitative analysis of students' before and after responses looks for whether ideas about intelligence have become richer and more complex. Students begin the AI adventure with varied states of beginning knowledge and therefore idea change must be considered for each individual. A rather unsophisticated view of intelligence equates it with having a lot of information. A somewhat more sophisticated idea of intelligence sees it as the same thing as smart. Some students begin to see smart in more nuanced and complex ways. Finally, a deeper understanding of intelligence can include ideas about problem solving, common sense, and multiple forms of intelligence. Table 1 presents examples of students' ideas about intelligence at the beginning and end of Room 1. The set of examples are arranged in a rough ordering based on the depth of beginning ideas. (Examples are exactly what students wrote with the exception of corrected spelling.)

Table 1: Initial and post Room 1 ideas about intelligence

Initial Ideas	Ideas after Room 1
Intelligence is someone or something that has great memory skills.	Intelligence can help people and animals how to solve everyday problems. Intelligence is a common thing in humans, animals, and computers to figure out problems in the future.
Intelligence means you're very smart or know a lot about something. This word is just a different word for smart meaning you know a lot.	I think intelligence is more what you learn and how you use it in your own little creative way. Whether it's to make a living or just to have fun being intelligent can help you in every way. I think intelligence means you just know a lot about something and you can talk a lot about that subject.
To me intelligence means making smart decisions and being a smart person.	Intelligence is the ability to think outside the box, solve problems, and create new things. There are many different ways to be intelligent.
Intelligence is how much you know and how smart you are.	Intelligence is the ability to acquire and apply knowledge and skills
Intelligence means a lot to me because without it I would walk around and make a fool of myself. With intelligence I can get good grades and always act smart.	Intelligence comes in many forms. It can either mean school smarts and common sense, or it can be in art, music, and animals have intelligence.

Intelligence means that you may be able to solve problems fast or in a quick amount of time. Intelligence is almost like being smart you know a lot of information that help create news things or fix old things.	Intelligence is being able to solve problems, adapting to new subjects, interacting with new people, and putting new and old things together to make new ideas. Intelligence is using what you know already to expand your knowledge even more. Intelligence means that you may be able to solve problems fast or in a quick amount of time. Intelligence is almost like being smart they are similar. Intelligence is being able to solve problems, adapting to new situations, interacting with others, and putting new and old ideas together to make new ideas. Intelligence is using what you know already to expand your knowledge even more.
Intelligence means that you have power to think something outside common sense. Intelligence does not include everyday routines that people are used to. Things like remembering song lyrics, math problems, lines in a play or movie and so on are all activities that require intelligence. You don't have to be a genius to be Intelligent.	My new idea of what intelligence is that everyone can be intelligent in something. Common sense is included in this. Intelligent people are all around us. They work in all types of jobs. Intelligence doesn't just mean you excel at something. Everyone is intelligent. In the future even robots will have some sort of intelligence. Common sense is what intelligent people have. If you aren't intelligent you can't do anything. We are intelligent when we brush our teeth or comb our hair.
Intelligence to me means being smart when it comes to common sense and even knowledge.	I think intelligence is not only being smart and having common sense, but I think intelligence is also getting along with others to get something done, and working hard using determination to achieve your goals. I mean, that right there, is an intelligent thing to do.
To me, intelligence means that you can problem solve, and help people when they need it. Intelligence also means that you can figure things out that others can't, and you challenge yourself.	I don't have a new idea to what intelligence is, but from doing those activities I have opened my range of what I think it is. Intelligence comes in many ways and forms, and it doesn't just mean that you're good at math. Intelligence means that you can comprehend things and then figure out a way to make that useful to you.
Intelligence, to me, is the ability to be able to solve problems, think, and create. To be intelligent you must be a thinking, problem solver	Intelligence is a universal thing that everyone, and everything has. Animals are intelligent as they can adapt and solve problems. There re many types of intelligence, like Art, Physical Abilities, etc. You must be able to solve problems, and be creative.
When I think of the word intelligence I think of smart but that has nothing to do with it. intelligence is the way we function and is the thing that makes us be able to do stuff and adapt stuff so what does it mean to me a lot because if we didn't have it we would not be able to do anything and the human race would be extinct.	My idea about intelligence was proven in the videos

The evidence here demonstrates that the Room 1 experience results in expanded ideas about intelligence. This is the case regardless of initial knowledge. Even learners who begin with

more advanced ideas about intelligence are able to build upon those ideas in substantive ways. Some students change their ideas entirely, sometimes eradicating misconceptions (e.g., the student who thought everyday thinking and common sense did not represent intelligence). There is also evidence that a broader conception of intelligence emerges. The new conception is one that could change students' mindsets[15] from fixed to more of a growth orientation (e.g., the student who concluded that intelligence involved "…working hard using determination to achieve your goals. I mean, that right there, is an intelligent thing to do.")

Room 2. Intelligent Machines Need Knowledge and Rules

The central idea in Room 2 is that intelligent machines need knowledge and they need rules to operate on that knowledge (later in Room 3 this idea is expanded by introducing the connectionism approach to cognition). After doing some thinking about machine intelligence, students encounter machines engaged in a variety of tasks (e.g., playing chess, expressing emotion, playing table tennis, dancing, solving Rubik's cube) and write what the machine needs to know to perform successfully. Table 2 shows students' ideas about what machines need to know.

Table 2: Student ideas about what machines need to know for different tasks

Task	Need to Know
Chess	Pick up and move the piece and press the button and know which pieces are theirs and when to move the piece and what each piece can do.
	You would need know how to play chess and you would have to program or teach the robot how to play chess.
Express emotion	Move face muscles, know why they are expressing emotion, know what emotion means what and when to express each emotion
	You would have program or teach the robot the feel emotion like how we feel emotion. Like if we are happy we feel happy
Table tennis	It needs to know where the ball is. Needs to know where to hit the ball. Needs to know how to hit the ball
	See where the ball is headed; calculate the coordinates of the ball's next course of direction; hit the ball at the precise time in the correct coordinates
	To play ping-pong, a machine needs to be able to see the ball, judge where it will end up, and hit the ball with appropriate strength
Dance	The robot needs to be able to move its body parts. It needs to be able to have balance And it needs to be able to comprehend stuff
	Sees where its going; knows where it wants to go or do what it wants to do; perform the movements it requires for doing that thing
Rubik's cube	See the colors know how to turn the blocks on the Rubik's cube know that the objective is to get all the colors on the right sides know a specific pattern to solve it
	Must know how to use a Rubik's cube; must "know" color; must understand how to finish the puzzle

The responses provide evidence that students can begin to think about what intelligent machines must "know" in order to perform particular functions. The ideas vary in sophistication. Some comments emphasize the knowledge dimension exclusively. In others the emphasis is all on rules or algorithms. But all students get beneath the surface and many begin to coordinate knowledge and process. These ideas form the basis for understanding the classical AI view of intelligent machine behavior and evidence shows that students are using them in their thinking and explanations.

V. Discussion

Meeting the Needs of Different Contexts

The creation of Through My Window is an ambitious undertaking consisting of many elements. Central to the project are illustrated novels that allow engineering concepts to be introduced and explored in depth. Through working with educators we have found that the current *Talk to Me* novel can be used in a variety of subject areas (including STEM, language arts and ESL) and contexts (including traditional classrooms, home schooling and many different types of informal settings). Based upon this feedback we have made flexibility a key design component. For example, the *Talk to Me* novel is available in a variety of formats including: online website, eBook, print book, audiobook with subtitles and an online Spanish translation.

The main focus of this paper is Rio's Brain--the first online learning adventure created for the project. Formative assessment in a variety of settings has shown both the potential and challenges of this approach. Clearly children are highly engaged and their ideas improve when they use the adventure. The online environment allows them to work at their own pace with little or no supervision, use multimedia tools and games to advance their thinking, revisit and repeat parts of the adventure; access their ideas and other items recorded in the electronic journal; and conveniently share their ideas and encounter the ideas of their peers. Utilizing such a powerful learning environment also creates challenges. Access to computers with sufficient bandwidth to support the video functionality may not be available to all teachers. We have also found that some teachers are initially uncomfortable with technology playing such a large role in the learning process and the independence it affords each learner.

The primary goal of the Team Through My Window website is supporting such a flexible approach to learning and supporting its use in contexts that range from advanced computer classrooms to settings with no technology. This website provides pathways showing how Through My Window can be adapted to be used in a variety of contexts, such as: only using the novel with discussion prompts; using the novel with offline activities that allow learners to further explore ideas introduced in the novel; using the novel with the online learning adventures; and using the novel, learning adventures and activities together. Although Through My Window contains many elements, common to all of them is the use of IE cognitive tools and idea-centered discourse to support deep learning.

Supporting Deep Learning

Through My Window shows how IE can be used in a variety of formats to engage learners to think deeply about ideas. This level of engagement is critical for meeting the learning goals that we have set out. It is through engagement that learners develop a deeper understanding of the

work of engineers and learn to see engineering as a subject that is interesting, understandable and worth pursuing. It is through participating in the narratives and engaging with new ideas that learners will change the way they see themselves relative to STEM disciplines. Finally, it is through engagement with the big concepts introduced in each learning adventure that learners will develop an understanding of some of the important ideas in engineering. Through My Window has just recently been launched. Much content still remains to be developed and the assessment has only just begun. However, evidence is already emerging that this application of IE not only gets learners to think and write about their ideas (no easy thing to do in any learning environment), but also has resulted in significant idea improvement for the learners (for example, see Table 1).

Another important challenge in designing the learning adventures is providing differentiated instruction that works for learners coming from a wide variety of entry points and with vastly different knowledge. As shown in Table 1, even when learners are from the same grade in the same school, their preconceptions differ greatly when they begin Rio's Brain learning adventure. Some are surprisingly sophisticated, while others are naïve. Thus a key design element of the learning adventure is creating a Zone of Proximal Development (ZPD) that is wide enough to provide the scaffolding that this range of learners needs to advance. For example, although all learners had a similar experience of videos, activities, scaffolds and prompts in Room 1, Table 1 shows evidence that the ideas for all users improved from where they started.

As do many fields, engineering education at both the pre-college level and college level emphasizes *efficiency* (the rapid retrieval and application of knowledge to solve problems). Schwartz, et al.[16] emphasize the need to balance learning experiences designed to support efficiency with learning experiences designed to support *innovation* (opportunities for experimentation and deep learning). It is these innovation learning experiences that help learners develop what Broudy[17] refers to as their interpretive knowledge; that is, the concepts we use to make sense of the world, to think about things and to ask the right questions. In the development of Through My Window we have tried to balance efficiency and innovation. For example, the second learning adventure currently in development is carefully aligned with the Next Generation Science Standards for engineering design. It supports the development of the replicative and applicative knowledge that is often measured on standardized tests. However, in all of the elements of Through My Window (including current and upcoming adventures), our primary interest is developing interpretive knowledge through innovation. Interpretive knowledge leads to developing STEM identity, understanding what engineers do and deeply understanding the big ideas in engineering subjects. Our evidence shows that the AI learning adventure can have an impact on interpretive knowledge. For example, in Room 2 learners encounter machines engaged in a variety of tasks requiring intelligence. Although these tasks were new to the learners, Table 2 shows that they were able to develop ideas about what machines need to know for each task.

VI. Conclusions

We have applied Imaginative Education to develop an online learning environment called Through My Window. The learning goals of Through My Window are to engage learners with engineering ideas, develop learners' STEM identity and help them to better understand what

engineers do. Although the website has been recently launched and the assessment program has just begun, there is preliminary evidence supporting the following results for the Rio's Brain learning adventure on artificial intelligence:

- The application of IE gets learners to think and write about their ideas and results in significant idea improvement.
- A Zone of Proximal Development has been developed that is wide enough to support a wide range of entry points for learners.
- The learning adventure supports the development of interpretive knowledge.

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