International Journal of Engineering Education Vol. 37, No. 6, pp. 1700–1715, 2021
Printed in Great Britain
0949-149X/91 $3.00+0.00

Telling Tales: The Development of a Storybook to Introduce Electronics to Engineering Undergraduates*

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Storytelling can be an effective pedagogical tool to transmit technical information and increase engagement. Storybooks are a visual medium where the technical content can be explored through narrative and imagery. A storybook was written and illustrated to translate the functionality of a breadboard and the process of making a circuit into a fictional narrative. Through observation and a quantitative assessment, this study explores the question: is a storybook as effective as a traditional lecture to transmit technical content? One section of a first-year engineering design course (n = 29) had a traditional lecture to learn about breadboards, and the other section (n = 43) used the storybook. Participants in both sections were timed to see how long it took to replicate two circuits. They completed a short assessment to measure their understanding of the functionality of breadboards. Participants who used the storybook completed the activities significantly faster ($p < 0.001$) and demonstrated a better understanding of the material (non-significant) than participants who received a lecture. Though the storybook was developed for audiences of all ages, findings of this study are limited to undergraduate engineering students.

Keywords: engagement; instructional methods; electrical engineering; active learning; storytelling

1. Introduction

Once upon a time, in a university not so different from our own, a professor was preparing a lesson for teachers who were coming to learn about electronics. Some of the teachers were comfortable using electronics, but some of the teachers didn't like electronics at all, so their students never learned how to use them.

"How can I make these teachers see that electronics aren't so scary?" the professor wondered while pacing in her office. "Using electronics might be new for them, but if I explain it well enough, I know they'll have fun!" So she sat down and wrote a story about a magical town called Breadboardia to show the teachers that using breadboards to make electronic circuits isn't hard at all! She turned the holes on the breadboard into houses in the town and made the rows of five holes into streets with five houses on one side. The red and blue power rails transformed into rivers of hot lava and water, and the gap in the middle became a great canyon dividing the town in two.

The next day, after the professor read the story, the teachers smiled and clapped. They used the breadboards, made circuits, and even made LEDs light up. The professor realized that there was something special about stories, and she vowed to explore just how powerful stories can be.

Stories *are* powerful tools. They transmit knowledge, forge connections between seemingly unrelated concepts, and captivate an audience in the process [1]. As educators, storytelling as a teaching strategy has the potential to make challenging topics more approachable. A lecture that begins with "Once upon a time" changes the perceived complexity of a topic, because those four words are linked to nostalgic feelings of childhood [2], not to an intimidating concept that might otherwise invoke fear. Additionally, using a different modality of learning, such as storytelling, heightens the curiosity and attentiveness of the audience [3, 4], simply because it is new.

The meta-story at the beginning of the paper illustrates the potential that stories have to convey information in a more engaging way than a recitation of facts. The K–12 teachers that attended the workshop participated in an experiential activity to power three LEDs using an Arduino, a breadboard, and electronic components. Though it would have been more typical to use a diagram to explain the functionality of a breadboard, the oral recitation of *Breadboardia* captured the teachers' attention and created excitement around an electronic component that is not considered exciting. After all, breadboards are simply plastic electronic prototyping platforms, but when combined with a story, breadboards are the setting for heroines and magical spells.

The teachers' positive reception of the story inspired the development of a storybook entitled *Breadboardia* to explain the functionality of breadboards through an illustrated narrative on the right-hand pages and the corresponding technical content on the left-hand pages. Sample pages are shown in Fig. 1. To engage readers further through experi-

* Accepted 18 July 2021.

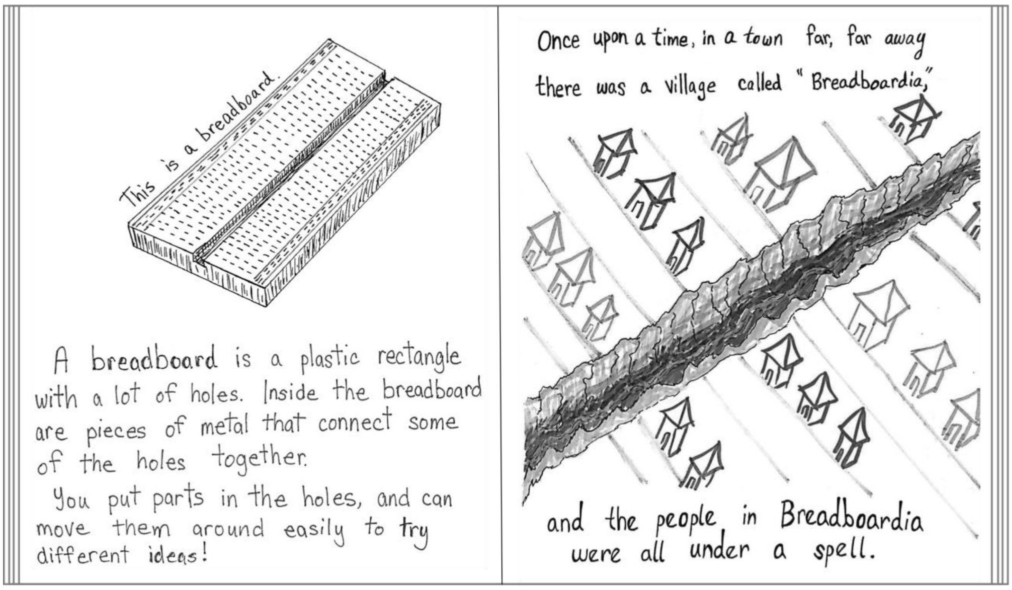

Fig. 1. Introductory pages from *Breadboardia*.

ential learning, the storybook was expanded to include the steps to make an electronic circuit that powers three LEDs.

This interactive storybook was developed for audiences of all ages, and was revised based on feedback from professional engineers and non-technical users including children and retired teachers. The storybook can be particularly useful in the engineering classroom to experientially convey an introductory electronics lesson in an engaging way. Therefore, a study was warranted to ensure it is an effective educational tool for undergraduate engineers. This paper documents the development of *Breadboardia* and the resulting study that explores the question: is a storybook as effective as a traditional lecture to convey technical information?

2. Background Information

2.1 Storytelling as Pedagogical Tool

Storytelling is an artform that is used in multiple ways in the classroom [1, 5]. In engineering, instructors use narrative to relate a topic of interest to a past experience, showing how the theory is applied in the real-world [6, 7]. Instructors use stories to explain how a concept was discovered or to convey the interesting circumstances surrounding the discovery [4]. An apple falling from a tree is a ubiquitous introduction to gravity, illustrating both the historical context of Newton's discovery and the concept of how gravity works.

Stories have the power to capture attention, translate the lesson to a relatable concept, and enable long-term retention, culminating in a deeper understanding of the topic [1, 8, 9]. Students have to be interested in a topic in order to learn it [10]. Using a more engaging form of delivery initiates the learning process to capture students' attention [8], but in a long, dull lecture, students' interest can wane [11]. Engineering education pedagogy is built on the desire to create an environment that supports students' ability to learn the material [12, 13].

Stories are engaging. Students participate with a story differently than they listen to a lecture [3, 10]. Woodhouse explains that through storytelling, teachers connect emotionally with students, "breathing life in the ideas that are being taught" [9, p. 211]. Abrahamson explains that methodologies should be "awakening and moving" experiences to make connections with students [14, p. 442]. Students are not static creatures, robotically waiting for input. Instead, they are multiform beings who require inspiration and motivation to engage with a topic [14]. Stories can meet the complex needs of students in ways that explanations cannot [9].

In addition to being more engaging, stories make embedded concepts more memorable [14, 15], as in Newton's apple. Students are able to remember information that is incorporated in a story better than information that is listed in a logical sequence [5]. Stories associate concepts with something familiar and help students see the interrelatedness of seemingly unrelated concepts [16, 17]. Then in the cognitive space, when one of the connected elements is recalled, the core meaning is also recalled [18]. If students become emotionally connected to the story, they can be compelled to retell the story [19]. Repetition of the story further reinforces the retention of the core concept. The combination of increased engagement, connection-making, and retention of the topic through storytelling allows students to learn the subject more thoroughly.

2.2 Byproducts of Storytelling

While the primary reason to use storytelling in the classroom is to convey technical content, there is an opportunity to imbue character-building skills within the story, such as resilience, reflection, and creativity [20–22]. Though not explicitly stated, a story can contain or "instantiate [meaning] though it is not 'in' the story" [23, p. 36]. In retelling a story about the development of a concept, instructors can include the struggles and failures that the protagonist had to overcome to succeed. Hong and Lin-Siegler found that by presenting struggle-oriented background information, high school students became more interested in science and solved more complex problems than students who received achievement-based stories [20]. Showing students examples of success through failure helps them develop resiliency.

When instructors tell a personal story, it may be misinterpreted as anecdotal or nostalgic. However, by listening to other people's stories, the listener can develop deeper wisdom and empathy and reflect on their own stories [24]. In this way, storytelling is a process and a way of thinking about the world [22]. Hearing stories about professional experience can help students envision their future job and what might be required of them.

Storytelling presents the opportunity for creativity and inquiry, both inside and outside of the classroom [25]. Creativity is newly being explored in the technical fields, evident in the transition from STEM to STEAM initiatives which now incorporate *art* along with *science, technology, engineering*, and *math.* Root-Bernstein and Root-Bernstein explain, "Math, science, and technology have flourished in the past only when and where the arts of have flourished" [26, p. 317]. Sochacka et al. build on the importance of incorporating arts into the curriculum, explaining that STEAM provides "students and educators with opportunities to explore personally relevant connections between materials, design, society, and the natural environment" [27, p. 15]. Storytelling is a natural incorporation of art into a technical curriculum and helps students make connections to the greater world, imbuing students with a sense of wonder [21].

2.3 Storytelling in the Classroom

There are documented examples of using storytelling to convey technical content in the K–12 settings and at the university level. Science topics were taught using storytelling in a Swedish Kindergarten [28], an English primary school [15], an American middle school [29], an Australian secondary school [30], and an American high school [31]. In England, storytelling was used in a multi-sensory experience for students with profound and multiple learning disabilities [32].

The discussion thus far has explored storytelling as a delivery method; storytelling can also be used by the students to demonstrate an understanding of content through creative expression. At the high school level, digital storytelling (a visual medium to communicate information electronically) was used in a maker space to create moving dioramas [33]. In a middle school computer programming course, girls used computer programming to visually tell stories [34].

Classes for English as a second or additional language (ESL/EAL) used storytelling to help students with varying levels of language ability express themselves. In Australia, ESL students in grades 3–6 used digital storytelling to produce their fictional stories [35]. A study in Canada documented how EAL teachers incorporated storytelling to support students who recently immigrated [36].

According to M. Rao, the role of storytelling has only recently been recognized in higher education [6]. Across the campus, there are documented examples of storytelling: (i) in the arts and humanities [25, 37, 38], (ii) in health sciences and nursing [39, 40], (iii) in business and accounting [41], (iv) in computer science and biology [1, 21], and (v) in engineering [8, 42–57].

2.4 Storytelling in Engineering

Storytelling is used in both the deliverables and the delivery method in engineering settings to convey technical information, design concepts, and professional skills [7, 8, 43]. Looking first at the technical courses, digital storytelling was used in a civil engineering lab as a deliverable [44]. As a delivery method, science fiction stories were used in a statics course [7]. Also a delivery method, an electronic tutor was developed with the appearance of a storybook for finite element modeling [45]. With the recent shift to online learning, storytelling has the potential to become an integral part of the instructional environment.

In gamification, the course is converted into a game with levels and challenges [46]. This re-envisioning of the course structure turns the entire course into a story with students as characters. Gamification has been documented in nearly every engineering discipline [8, 46, 47], showing the pervasiveness of storytelling in engineering.

To develop professional skills, examples of highly interactive delivery methods include the use of an escape room to introduce students to engineering information [48], improvisational games for technical communication [49], and role-playing to teach quality control [50]. In ethics courses, storytelling is commonly found in case studies to promote ethical behavior and can also develop leadership skills [51]. In one ethics course, single-decision point situations were made more interactive with the use of video games putting students in the role of the protagonist and providing multiple points for decision-making [43]. Adapting an approach found in a storybook, one ethics course incorporated a "choose-your-own-adventure" activity [52] to allow for multiple opportunities for decision-making.

Narrative, a form of storytelling that incorporates reflection on personal experiences, is used as both a process and a product to integrate leadership skills and frame the role that students might have within the engineering profession [53]. As one of the ABET criteria, storytelling is poised to help students understand their role in the profession, and was used in a mentoring capacity to transfer knowledge in the workplace [54]. Secules describes the use of narrative to support students who are marginalized within engineering, concluding that the use of naming can empower students to be able to see and tell their own stories [55].

In design courses, storytelling was used to help students learn the design process through human-centered design [56] and focus on understanding the problem [42]. As a deliverable, storytelling was used in the design pitch for students to learn how to communicate their design [57] and through digital storytelling to document engineering process skills [58]. The broad concept of storytelling has been incorporated through ethics, design, and technical courses in the engineering university curriculum.

2.5 Storybooks

Storybooks, a visual form of storytelling, combine text with images to make learning more interesting and interactive. Spiegel et al. found that high school students were more likely to prefer comic books over essays to learn science concepts, and both methods resulted in comparable knowledge scores [31]. In middle school science classes, the use of storybooks increases students' scientific literacy and critical thinking skills [30] and makes learning more memorable [15]. At the time of writing this paper, no examples were found in the literature that use storybooks specifically to deliver technical content at the university level. This is a missed opportunity. Yu explains:

> "Contemporary readers, especially young readers, have become accustomed to multimodal communication through their daily exposure to TV, film, and the Internet. These readers will increasingly expect multimodality in areas that are traditionally dominated by word-based texts, such as technical communication" [59, p. 20].

Especially with the rise in popularity of graphic novels, students are familiar with the storybook medium. Instructors at the university level have an opportunity to present technical content to students in a way in which they are already accustomed.

The multimodality inherent in storybooks encompasses multiple learning styles to engage more students [21]. Learning styles denote a *preference* towards a particular type of knowledge acquisition [60] or a combination of preferred learning styles [61] rather than a particular ability. Examining the multimodality of a storybook using the VARK model of learning styles [62], a storybook could be read out loud (aural) while students follow along (visual and reading), then apply learning through an activity (kinesthetic). Arguably, the same learning styles can be addressed in a lecture with slides and an activity, though with less interactivity. However, the interactivity inherent in active learning has been shown to be more effective than lectures for understanding more complex concepts and to transfer knowledge to different settings [63]. According to Prince, a defining element of active learning is engaging students in the learning process, as opposed to the traditional lecture "where students passively receive information from the instructor" [64, p. 223]. Examples include flipped classrooms, hands-on labs, problem-based learning, design projects, and specific examples cited in the previous section such as gamification and ethics scenarios [8, 46–58, 63–65]. Active learning is shown to increase engagement, comprehension, and retention of material [63–65] and is a cornerstone of engineering education pedagogy. A novel form of active learning is to use storybooks at the university level to convey technical content. Storybooks have the potential to allow students in large classes to have multi-modal, meaningful active learning experiences.

Potential drawbacks have been found at the K-12 level for using storybooks to convey technical content. Rowcliffe warns against the overuse of the anthropomorphism that can be found in fictional stories that give inanimate objects human characteristics, admitting it can be patronizing, unscientific, and open to misinterpretation [66]. Expanding on Rowcliffe's third point, Walan advises that using storytelling to transmit scientific information has the potential to spread "faulty science" if there are misconceptions [28, p. 36]. To prevent students from feeling patronized, storytelling should be consistent with other aspects of an instructor's teaching style, and students must be receptive to this non-traditional method. Bolkan recommends that stories should be *concrete, course-oriented*, and linked to students' *personal experiences* [67]. This can reduce misinterpretation and increase engagement.

3. Development of the Storybook

3.1 Storybook Design

Following Bolkan's recommendation, the storybook should be course-oriented, linked to students' personal experiences, and concrete [67]. In order for the storybook to be *course-oriented*, learning objectives were developed. To be linked to students' *personal experiences*, the storybook must be accessible to a broad audience. To be *concrete*, the learning objectives are repeated throughout the storybook and communicated using simple, clear language.

The storybook *Breadboardia* is 72 pages long and includes three chapters. To ensure the story is accurate but not overly complicated, the plot contains analogous language for parts of a breadboard and technical names for components. The left pages display simplified technical descriptions, and the right pages contain the analogous story for how a breadboard works. For example, *row*, *hole*, and *positive and negative power rails* are described on the left pages, and the corresponding *street*, *house*, and *rivers of lava and water* are incorporated in the story on the right pages. The analogy is necessary because readers may not encounter power rails, but they are familiar with cool rivers and flowing hot lava, connecting two seemingly unrelated concepts [16, 17]. To convey electronics content and help readers become comfortable using technical language, the names of components (*resistors, Arduinos*, and *LEDs*) were used on both left and right pages.

The first chapter entitled *The Town of Breadboardia* explains the basic functionality of the breadboard through a fictional story. The geographical layout of a town is explained wherein a magical spell confines people to their street and allows only one task to occur on each street, such as carrying packets, sharing messages, or passing power along. Fig. 1 shows pages from chapter 1. The second chapter entitled *A Very Clever Girl* introduces an Arduino-nano as a communication tool that is dreamed up by a clever girl who wants to make her town better. Additional concepts are introduced on wires, power flow, and schematics, and the chapter provides step-by-step instructions on how to light up an LED on the Arduino-nano that is pre-loaded with a specific program. The third chapter entitled *Light Up the Sky* explains how the people on the different streets can work together to make three LEDs light up with page-by-page instructions. Concepts introduced in this chapter include LEDs, resistors, programming, safety, troubleshooting, analog and digital. Fig. 2 shows pages from Chapter 3 of one of the final steps, with the schematic and instructions on the left page and the accompanying story on the right page. The book concludes with a glossary incorporating simple language to explain electronic concepts, such "a program is a list of tasks using words the Arduino can understand." The language is simplified to make the content less intimidating and so the storybook could be used for any age group that can read.

The objectives for the storybook are classified as: technical, abstract, functional, and complementary and are listed in Table 1. The primary technical objectives are content-specific, focusing on the

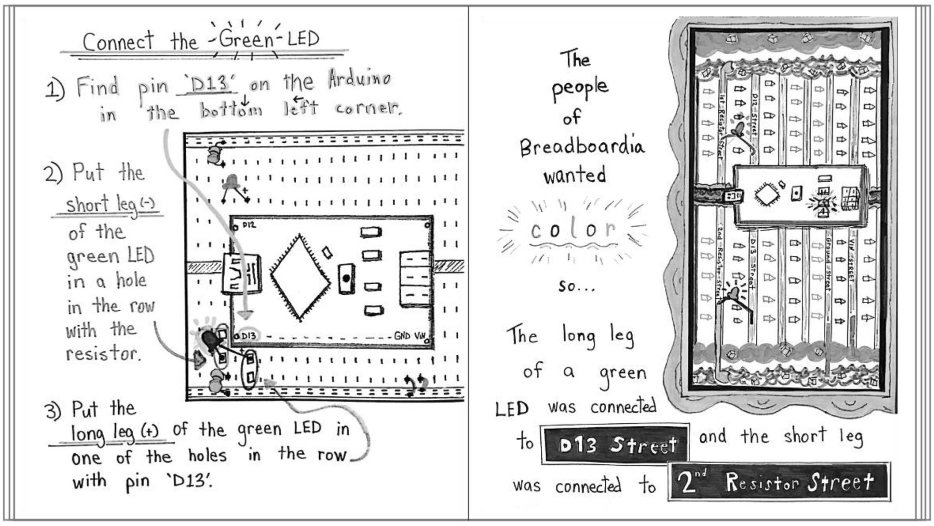

Fig. 2. Sample page showing schematic and accompanying story.

Table 1. Objectives of the storybook

Identifier	Description
Technical learning objectives for readers	
1a	Explain what a breadboard is & why it is used
1b	Identify which holes on a breadboard are connected
1c	Differentiate positive & negative power rails
1d	Explain how each row can have only 1 purpose
1e	Include steps to complete a circuit to light 3 LEDs
Abstract objectives of the storybook	
2a	Translate electronic concepts in an engaging and memorable way
2b	Empower the reader to feel comfortable using electronics
2c	Include opportunities for failure, persistence, & resilience
2d	Demonstrate what it means to be civic-minded
2e	Demonstrate the benefits of team-work
2f	Demonstrate a safety-oriented mindset
2g	Spark creativity so the reader can adapt the circuit to their own design
2h	Engage curiosity of the reader to problem-solve in their world
Functional objectives of the storybook	
3a	Feel like a storybook
3b	Ensure technical content is accurate
3c	Lay flat when open
3d	Ensure steps for building the circuit are clear
3e	Have visually engaging artwork
3f	Use simple graphics & handwritten font (reinforcing the simplicity of the activity)
3g	Use consistent language for story & technical content
3h	Have a straightforward but interesting plot
3i	Increase expectations throughout story (few instructions for 3rd LED)
Complementary technical learning objectives for readers	
4a	List types of components
4b	Define the following components & why they are used: Arduino, resistor, LED & jumper wire
4c	Identify functions of pins on Arduino
4d	Learn how wire transmits electricity through a solid wire
4e	Understand the role of a battery in a circuit
4f	Define the following concepts & why they are useful: circuit, program & trouble-shooting
4g	Differentiate analog vs. digital & provide an example
4h	Identify the positive & negative legs of an LED

functionality of a breadboard and how to complete a circuit. These objectives appear on both the right pages (the story) and left pages (technical content and definitions) and are repeated throughout the book, as they are the most critical outcomes. Fig. 1 corresponds to objective 1a. and Fig. 2 shows an example step corresponding to objective 1e.

The secondary abstract objectives focus on abstract qualities such as resiliency, determination, creativity, and civic responsibility. These are the qualities that link to competencies required by accrediting bodies, such as an ability to design with consideration for the needs of the public, the importance of team-work, and having a safety-oriented mindset for problem-solving [68, p. 5]. Through the story, readers learn to solve problems to help the community and to persist through trials, which the literature suggests can help students build resiliency [20], civic-mindedness [27], and creativity [25]. The sample pages in Fig. 3 demonstrate a safety-oriented mindset (objective 2f).

The tertiary functional objectives focus on the physical storybook: to ensure it lays flat for ease of use, is visually appealing to engage the reader, and has clear steps that are easy to follow. The graphics are intentionally simplistic, and the font is hand-written to subliminally reinforce the simplicity of the activity. If *Breadboardia* feels like a child's storybook, then the content within will not be perceived as complex.

The final objectives are complementary technical learning objectives that provide readers with additional electronics knowledge but are not necessary to complete the activity, such as the purpose of resistors (shown in Fig. 3) or the difference between analog and digital. An understanding of resistors is not crucial to the plot or activity, but providing the additional information engages a more knowledgeable audience. The complementary technical objectives are summarized in the glossary at the back of the storybook and appear once in the story.

3.2 Storybook Review

The storybook was revised twice during its development for: (1) accuracy, (2) accessibility, and (3) clarity. As the storybook is intended to be a non-threatening and engaging introduction to electronics, it has to be accessible to a wide audience from reading-age children to adults. Therefore, the language of the storybook must be appropriate for non-technical audiences yet retain the necessary depth and accuracy of concepts.

The first review was performed by three professional engineers for accuracy and accessibility, and the second review was performed by non-technical users for clarity. One recommendation from professional engineers was to use consistent language that is understood by children, such as *power* in place of *energy, current*, and *voltage*. This presented challenges when describing resistors and 9-Volt batteries but was necessary for accessibility. Similarly, the word *messages* is used because it is more universal than *data*, though admittedly less technical.

The non-technical users consisted of children

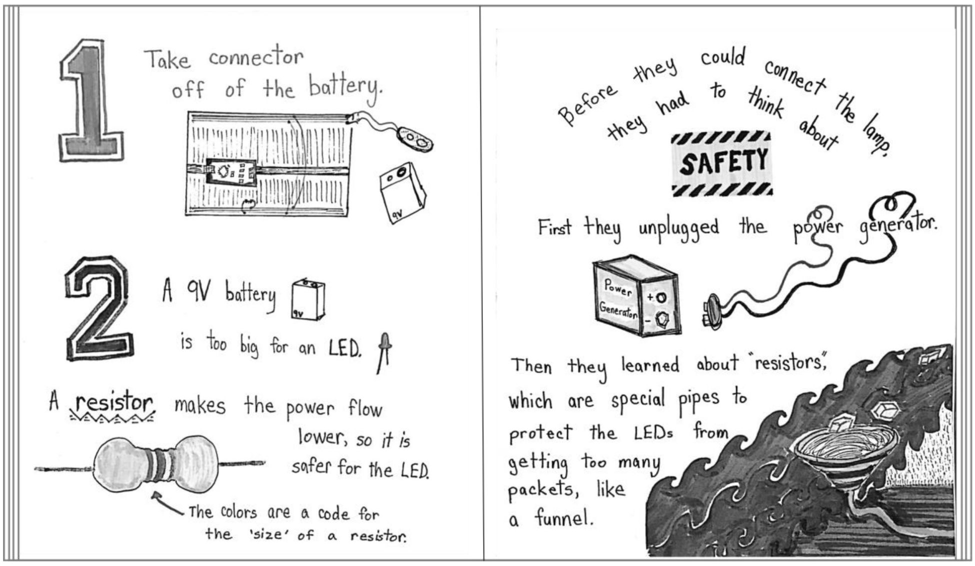

Fig. 3. Sample pages about safety and resistors.

between the ages of 6 and 13 and retired teachers; they evaluated whether instructions were easy to follow, and technical descriptions were understandable. Based on their feedback, a definition for *breadboard* was added to the beginning, and a glossary was added at the end. The storybook was divided into chapters with keywords and parts lists. Users were able to construct the circuit using the steps provided, however, children had trouble inserting components that were grouped together. The storybook was revised to distribute the LEDs across the breadboard, necessitating the addition of a jumper wire. Abstract objectives were revised to include safety, and instructions were added to prevent common errors. Once the storybook was reviewed for accuracy, accessibility, and clarity, it could be used as an instructional tool to explore whether storybooks are an effective delivery method at the undergraduate level.

4. Method

4.1 Methodology

Employing a positivist approach, empirical data were collected through observation and testing at the University of Prince Edward Island in Canada to determine whether the primary technical objectives were met. A non-probabilistic purposive sample was used of engineering students in a first-year design course who had limited experience with breadboards and electronics. Data were collected in a "one-shot" manner rather than longitudinally [69, p. 140].

4.2 Sampling

One section of students (n = 29) represented the control group and received a brief (10–15 minute) lecture with accompanying slides. The lecture contained visually engaging slides with all of the technical and complementary learning objectives shown in Table 1 (objectives with numbers 1 and 4). The other section (n = 43) represented the experimental group and followed along with coil-bound copies of the storybook while the right-hand story pages were read aloud instead of a lecture. Following the intervention, both groups participated in a two-stage activity. The times were recorded for each participant to complete a circuit to light up one LED, then to light up three LEDs. Participants completed a short assessment to measure their knowledge of breadboards and document demographic data.

Whereas the participants in the storybook group had step-by-step instructions built into the book, the participants in the lecture group were shown two images to replicate with basic instructions. Fig. 4 shows the slide containing part two of the activity to light three LEDs which was projected for the lecture group. The schematic shown in Fig. 4 is taken from the back cover of the storybook and demonstrates the final goal for the storybook group.

4.3 Research Question

Is a storybook as effective as a traditional lecture to convey technical information? Time to complete the activity and knowledge of breadboards were used to quantify the *effectiveness* of the delivery method. One drawback of active learning is that interactive methods can take more time than lectures [70]. Because class time is a precious commodity, one measure of effectiveness is a shorter duration. While the lecture and recitation of the storybook had

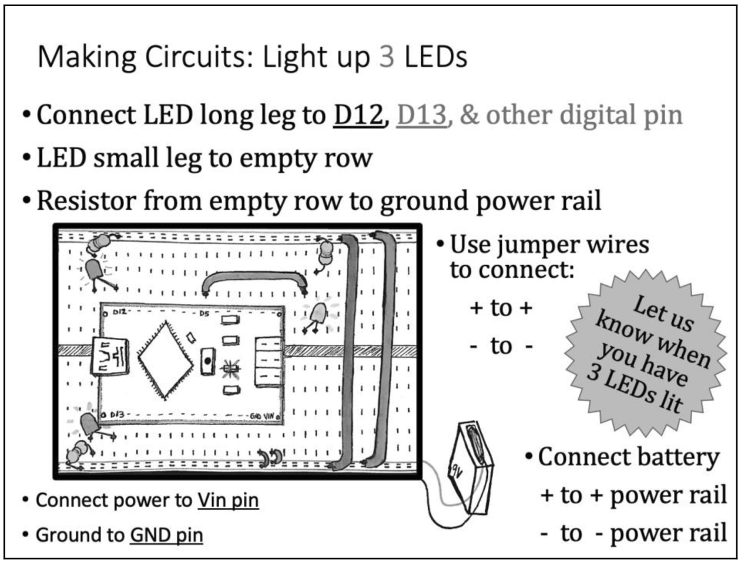

Fig. 4. Image provided for participants in lecture group.

similar durations, the activity that follows was timed. It was anticipated that the activity would take longer for the storybook group, because participants would spend more time reading and methodically turning pages. The lecture group were given images to replicate, so it was anticipated that they would not be distracted by the extraneous details of the story.

The second measure of effectiveness is demonstrated knowledge of the primary learning objectives. A higher score denotes a higher expertise. Lectures allow the instructor to plainly state what students should know about a topic, reinforced by the content in the slides. For the storybook, learning objectives are embedded within the story and are therefore less explicitly conveyed. The benefits of active learning suggest the pertinent information will be translated from the story to important technical knowledge, but this uncertainty creates the need for this study. There was no hypothesized outcome for *knowledge.*

4.4 Ethical Considerations

Complying with an approved research ethics protocol, the script outlining the consent process was read at the beginning of class. Participants were seated at numbered desks to connect their times with their assessments and to allow anonymous withdrawal from the study, which one student elected to do. The groups were not informed which section utilized the novel approach to ensure that both groups had similar motivations during the activity. The control group preceded the experimental group to ensure any cross-talk between groups did not alter the second group's expectations.

4.5 Instrument

The demographic portion of the instrument consisted of three multiple-choice items documenting gender identity, prior experience with breadboards, and enjoyment level. The assessment portion of the instrument consisted of three open-ended items and two multiple-choice items to measure knowledge of breadboards. The assessment items were converted to twelve binary-scored dependent variables and were coded (1) for incorrect and (2) for correct.

The response for open-ended item 1 'What is a breadboard' (objective 1a in Table 1), was reviewed for references to (i) form, (ii) fit, (iii) function, (iv) prototyping, and (v) electronics and coded into five separate variables. A total score out of 5 was computed these variables for Q1 ($M = 2.99$, $SD = 1.04$).

The response for open-ended item 2 'What is the red rail generally used for' (objective 1c), was reviewed for references to (i) power and (ii) positive polarity and coded into two variables. A total score out of 2 was computed for Q2 ($M = 1.35$, $SD = 0.55$).

In the three items that form the third question, participants identified which of the seven numbered holes on a sample breadboard image were connected (objective 1b). The two multiple-choice items asked participants to confirm whether specific pairs of holes were connected, which neither were. The open-ended item asked participants to list the remaining connections, and the responses were coded into three variables: (i) identification of the first pair of holes, (ii) identification of the second pair, and (iii) whether additional pairs were selected (reverse-scored). A total score out of 5 was computed for the Q3 variables ($M = 3.01$, $SD = 1.59$)

with reliability of scale (α = 0.72), suggesting internal consistency within the items. Reliability of scale was not evaluated for the computed Q1 or Q2 variables because the items within each variable were not repeated measures but rather elements within a single item.

A total *knowledge* score (M = 7.39, SD = 2.23) was computed by summing Q1, Q2, and Q3 with a maximum value of 12. The reliability of scale (α = 0.60) does not meet minimum standards (> 0.7), suggesting a low internal consistency [71]. This result is expected due to the low sample size and seven of the items are not repeated measures but rather elements within two items.

4.6 Participant Data

Of the 72 participants, 21 identify as female (29%) and 50 identify as male (69%). Participants could also select non-binary or 'in my own words', but these options were not selected. One participant did not respond to the demographic items. There was a similar female to male ratio between the two groups as 28% of the control group and 30% of the experimental group identify as female. This sample is reasonably representative of a typical engineering class. According to Engineers Canada, female students comprise 21.8% of the engineering student population, though the percentage varies by discipline (14.2% to 47.5%) [72].

Participants rated how much they *enjoyed* the activity based on a five-point scale from (1) *never again* to (5) *great!* (M = 4.72, SD = 0.54). Only one participant (1%) selected a number less than four. He was in the control group and had no prior experience with breadboards. Seventeen participants (24%) selected (4) *This was fun*, and 53 participants (75%) called the activity (5) *great!* Participants in the control group had an average of 4.54, and participants in the experimental group had a 5% higher average of 4.77.

Participants selected how many times they used a breadboard prior to the activity on a four-point scale: (1) *no experience*, (2) *once*, (3) *a few times*, and (4) *many times* (M = 1.76, SD = 1.20). Both novice groups, by definition, have an experience level of 1.0. A comparison of the experience level between the control group and the experimental group for participants with prior experience yields that participants with prior experience who received a lecture (M = 3.40, SD = 0.52) have a 5% higher average experience level than participants with prior experience in the storybook group (M = 3.17, SD = 0.93).

It is anticipated that participants with previous experience will perform better than novice participants, and their data can confirm content validity. Because the sample size is not large enough to warrant a 4-point scale, the *experience* scores of participants were recoded into a 2-point scale (M = 1.32, SD = 0.47) with the value (2) signifying *any experience* (32%). This includes the 4 participants with one experience (6%), 8 participants with a few experiences (11%), and 11 participants with many experiences (15%). The scores for the 48 novice participants (67%) retained a value of (1) signifying *no experience*. Chi-square tests determined there were no correlations between gender, experience level, enjoyment level, and the participant group.

4.7 Analyses

The independent variable is the [delivery] *method* and is coded: (1) for lecture (control) and (2) for storybook (experimental). *Experience* is a moderating variable. The dependent variables are the coded individual *knowledge* items, the summed *knowledge* scores, and the *times* to complete the activity. Two discrete ratio variables for the time to complete the two parts of the activity were recorded: (1) time to light 1 LED and (2) additional time to light 3 LEDs. A *total time* variable was computed (M = 18.9 minutes, SD = 10.37). For the *time* variables, a lower time indicates a higher ability, whereas for *knowledge* variables, a higher score denotes a higher ability.

To calculate the summed effect of time and knowledge, the *total time* was converted into a percentage out of 45 minutes and reverse-coded (M = 57.9, SD = 23.05) and added to the percentage value of the *total knowledge* (M = 61.6, SD = 18.62). This *effectiveness* score (M = 59.5, SD = 16.47) could be used to compare the overall participant performance.

The three ratio *time* variables, four ordinal summed *knowledge* variables, 12 categorical individual *knowledge* variables, and the ratio *effectiveness* variable were cleaned and reviewed for normality considering outliers, skewness z-score, and kurtosis z-score [73, p. 113]. Assumptions of independence of observations and equality of variances were reviewed for each t-test and analysis of variance (ANOVA).

Using SPSS for data analyses, Pearson product moment correlations were performed to determine whether *total time* and *total knowledge* are related (two-tailed significance at 0.05). A two-way ANOVA was performed between the independent variable *method*, the moderating variable *experience*, and main dependent variables: *effectiveness, total time*, and *total knowledge*.

While the data from participants with experience is useful for validation purposes, only novice participant data (n = 48) was used to evaluate the effect of using a storybook instead of a lecture. T-tests were performed for novice participants between the *method* and the four summed *knowledge* variables,

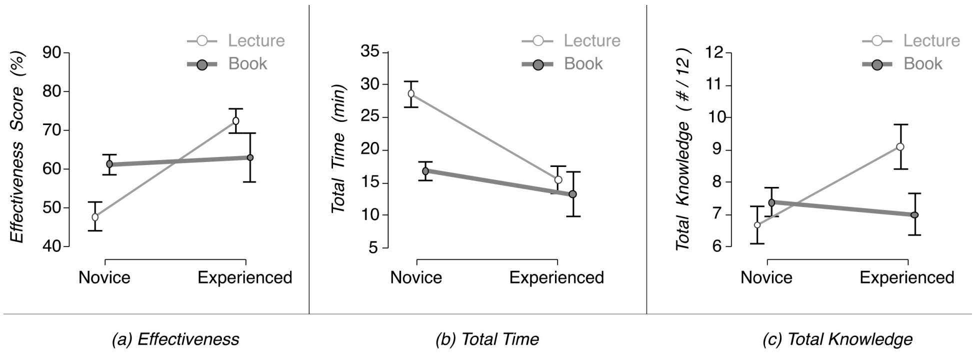

Fig. 5. Effect of *experience* and *method* comparing mean scores and standard error bands. Plots generated using JASP [74].

three *time* variables, and *effectiveness* variable. Chi-square tests were performed between the *method* and twelve individual *knowledge* variables.

5. Results

5.1 Correlation between Time and Knowledge

Using the Pearson product moment correlation, there is a statistically significant negative correlation ($r(57) = -0.30$, $p = 0.025$) between the *total time* and *total knowledge* dependent variables, wherein a faster time correlates with a higher knowledge score. This finding supports the use of faster time and higher knowledge as measures for effectiveness.

5.2 Moderating Effect of Experience

Using a two-way ANOVA, it was determined that the combined effect of *method* and *experience* has statistically significant interactions for the participants' *effectiveness* score ($F(1, 53) = 7.96$, $p = 0.007$, $\eta^2_p = 0.131$), *total time* ($F(1, 67) = 4.37$, $p = 0.04$, $\eta^2_p = 0.061$), and *total knowledge* ($F(1, 53) = 5.49$, $p = 0.023$, $\eta^2_p = 0.094$). Using partial eta-squared calculations, these results have a moderate effect size [69, p. 618]. Fig. 5 shows the mean scores for *effectiveness* (higher score desired), *total time* (lower number desired), and *total knowledge* (higher score desired) with standard error bands incorporated.

The *effectiveness* score (shown in Fig. 5a) reveals a statistically significant ($p < 0.001$) difference in scores for participants who received the lecture (denoted by the thin line) wherein participants with prior experience (M = 72.4, SD = 9.02) performed 25% better than novice participants (M = 47.7, SD = 15.1). The effect of experience for the storybook delivery method (thick line) was not significant ($p = 0.82$), though the participants with experience had a 2% higher mean score than novice participants. For novice participants, the storybook group had a statistically significant ($p = 0.014$) higher score (M = 61.2, SD = 11.9) than the participants who received a lecture (M = 47.7, SD = 15.1). For participants with experience, though not statistically significant ($p = 0.24$), the subset who received a lecture performed 9% better than the subset who used the storybook.

For the *total time* (shown in Fig. 5b), novice participants who used the storybook (M = 16.8, SD = 8.12) completed the activity 12 minutes faster ($p < 0.001$) than novice participants who received a lecture (M = 28.6, SD = 8.12). The difference in means was not significant ($p = 0.32$) for participants with prior experience, with a difference of only 2.3 minutes between the *method* groups. There were also significant effects ($p < 0.001$) for the participants that received a lecture between participants with prior experience (M = 15.5, SD = 6.57) and novice participants (M = 28.6, SD = 8.12). The effects were not significant ($p = 0.66$) between *experience* of participants who used the storybook, as the difference in mean times was 1.3 minutes.

For the *total knowledge* score (shown in Fig. 5c), participants with prior experience who used the storybook (M = 7.00, SD = 2.14) had a statistically significant ($p = 0.044$) lower knowledge score than participants with prior experience who received the lecture (M = 9.11, SD = 2.09). The novice participants had the opposite finding, where the mean score for the storybook group (M = 7.38, SD = 2.04) was 6% higher than the lecture group (M = 6.69, SD = 2.30), though non-significant ($p = 0.404$). For participants who received the lecture, novice participants (M = 6.69, SD = 2.30) had statistically significant ($p = 0.015$) lower scores than participants with prior experience (M = 9.11, SD = 2.09). There were no statistically significant differences ($p = 0.814$) between participants who used the storybook, though the novice participants performed 3% better than the participants with experience.

5.3 Effectiveness Score for Novice Participants

Comparing the performance of novice participants based on *method*, Table 2 summarizes the findings

Table 2. Effectiveness, time, and knowledge scores for novice participants

Variable	t	df	p	η^2_p	Lecture M (SD)	Storybook M (SD)
Effectiveness (%)*	–3.06	35	0.004	0.21	47.7 (15.1)	61.2 (11.9)
Total time (min)**	4.857	46	< 0.001	0.34	28.6 (8.12)	16.8 (8.12)
Time to light 1 LED (min)**	5.822	46	< 0.001	0.42	21.0 (6.26)	10.9 (5.58)
Additional time to light 3 LEDs (min)	1.206	46	0.234	0.031	7.56 (5.22)	5.93 (4.04)
Total knowledge (#/12)	–0.97	35	0.339	0.026	6.69 (2.30)	7.38 (2.04)
Q1 (#/5)	–0.358	46	0.722	0.003	2.67 (1.09)	2.97 (1.03)
Q2 (#/2)	–0.636	35	0.529	0.011	1.31 (0.60)	1.43 (0.51)
Q3 (#/5)	–0.956	46	0.344	0.019	2.67 (1.78)	2.83 (1.42)

Significance value * $p < 0.01$, ** $p < 0.001$.

from t-tests. Participants who used a storybook had a 13.6% higher *effectiveness* mean score ($p = 0.004$) than participants who received a lecture, with a large effect size ($\eta^2_p = 0.21$).

5.4 Total Time for Novice Participants

The mean *total time* for participants who used the storybook is 12 minutes faster ($p < 0.001$) than for the participants who had a lecture. This is contrary to the expected result and highlights the effectiveness of a storybook. The mean *time to light 1 LED* was 10 minutes faster ($p < 0.001$) for the storybook group than the lecture group. There were no statistically significant differences between the mean *time to light three LEDs*, but the storybook group completed the activity 1.6 minutes faster than the lecture group.

5.5 Total Knowledge for Novice Participants

The *total knowledge* score for participants who used the storybook was 6% higher than for students who received a lecture ($p > 0.05$). Similarly for Questions 1, 2, and 3, the storybook group's mean knowledge scores were 6%, 6%, and 3% higher, respectively, than for the lecture group ($p > 0.05$). Using Chi-square tests, two of the twelve individual *knowledge* items revealed a significant relationship with *method*, as shown in Table 3.

For the first question on the definition of a breadboard, participants in the storybook group mention the *form* of a breadboard 36% more often ($p = 0.011$) than participants in the lecture group, with a medium effect ($\varphi = 0.36$) [69, p. 654]. Of the five items in Q1, participants who used the storybook mentioned the form, fit, and prototyping aspects more often. In contrast, participants who received a lecture mentioned the function and electronic applications more often ($p > 0.05$).

For the second question concerning the red rail, participants who used the storybook all mention *power* compared to 75% of participants who received a lecture ($p = 0.015$), which had a

Table 3. Individual *knowledge* variables for novice participants

Variables	χ^2	df	N	p	φ	Lecture % correct (SD)	Storybook % correct (SD)
Q1: What is a breadboard							
Form*	6.40	1	48	0.011	0.37	11% (0.32)	**47**% (0.51)
Fit	0.49	1	48	0.527	0.09	61% (0.48)	**70**% (0.50)
Function	0.28	1	48	0.598	0.08	**89**% (0.32)	83% (0.38)
Prototype	0.16	1	48	0.688	0.06	28% (0.46)	**33**% (0.48)
Electronics	1.09	1	48	0.296	0.15	**78**% (0.43)	63% (0.49)
Q2: What is the red rail generally used for							
Power*	5.89	1	37	0.015	0.40	86% (0.45)	100% (0.00)
Positive	0.65	1	37	0.419	0.13	**56**% (0.51)	43% (0.51)
Q3: Connections on a breadboard							
Holes 1&2 (multiple-choice)	0.03	1	48	0.870	0.02	**72**% (0.46)	70% (0.47)
Holes 3&7 (multiple-choice)	2.73	1	48	0.099	0.24	67% (0.49)	**87**% (0.35)
Holes 2&5 (open-ended)	2.73	1	48	0.099	0.24	**33**% (0.49)	13% (0.35)
Holes 6&7 (open-ended)	0.59	1	48	0.441	0.11	56% (0.51)	**67**% (0.48)
Additional pairs (reverse coded)	0.28	1	48	0.599	0.08	39% (0.50)	**47**% (0.51)

* Significance value $p < 0.05$.

medium effect (φ = 0.40). Though non-significant, participants who received the lecture were more likely to mention the positive polarity than participants who used the storybook.

For the third question concerning the breadboard's functional layout, participants in the storybook group correctly identified two pairs (holes 3&7 and 6&7) more often ($p > 0.05$), whereas participants in the lecture group correctly identified the other two pairs (1&2, 2&5) more often ($p > 0.05$). Each group identified one multiple-choice item and one open-response item better than the other group, which eliminates the style of question as the cause for the difference. Participants in the lecture group proposed 4% more erroneous pairs ($p > 0.05$) than participants in the storybook group.

6. Discussion

6.1 Effectiveness for Novice Participants

Overall, the storybook was shown to be more effective than the lecture, which supports the hypothesis. The sample was generally representative of the larger engineering population and the *effectiveness* and *timing* data were statistically significant with medium to large effects. Thus, the findings can be generalized for undergraduate engineering students.

Non-significant findings indicate that the difference in means could be a coincidence, so the *knowledge* data cannot be generalized to the larger engineering population. However, it can be stated that for this particular group of students who did not have previous experience with breadboards, the storybook group (n = 30) scored higher on all of the summed *knowledge* questions than the lecture group (n = 18). This is an encouraging finding that this particular storybook can be used instead of a lecture to teach breadboard concepts for university students.

This study suggests that the higher *knowledge* score (though non-significant) can be attributed to the incorporation of active learning through the storybook in the introduction to electronics. Whereas active learning is present in the activity for both the lecture and storybook, the lecture provides fewer ways to engage in the introduction to the activity. The literature suggests storytelling has the potential to increase engagement and make connections with the students [9, 14]. The shorter time duration supports these findings as the students who used the storybook completed the activity faster. A follow-on study to consider the long-term retention and connection to the story could confirm these findings.

The non-significant *knowledge* findings may be attributed to the incorporation of active learning in the activity for both the storybook and the lecture. The difference in means may have been greater if the participants completed the assessment before completing the activity. This would remove any active learning effects from the lecture group. However that would evaluate whether active learning is effective, which has been documented [8, 46–58, 64, 65, 67]. Since the focus of this study is centered on the effectiveness of the storybook, it was important to compare what would naturally happen in a class: a lecture followed by an application versus a storybook followed by an application.

6.2 Time Advantages

One of the noted drawbacks of active learning is the increased time as compared to a traditional lecture [70]. Therefore, it was unexpected that participants who used the storybook take less time to complete the activity. This effect could be attributed to the step-by-step instructions incorporated in the storybook, reducing the troubleshooting time. One key advantage of the storybook is the access to instructions, as a standard lecture is not as likely to be accompanied by printed instruction booklets. There is an effect that is propagated from the *time to light 1 LED* to the *total time* to the *effectiveness* score. It should be noted but does not invalidate the data because the other measures in the summed variables could have a counter effect.

6.3 Instrument Design

There was variability between the individual items within the summed *knowledge* scores, which necessitates either a revision to the instrument as the items are poor measures or a modification to the storybook to emphasize the points that were not transmitted as clearly. The response rate for the second item regarding the power rail was 21% lower than for other questions, indicating either a difficult item that was intentionally skipped or a poor instrument layout wherein participants did not see the item.

Question three required participants to think about the internal connections on a breadboard, after they spent the activity connecting wires between holes that were not connected. This question asked them to invert their thinking, which is a higher-order process, and the instrument could be revised to emphasize the *internal* connections. Interestingly, the participants that used the storybook had more correct answers for the holes in the rows but fewer correct answers for the holes in the power rails.

6.4 Storybook Evaluation

As described in the literature, stories have the power to be more engaging [1, 5, 8, 9]. While engagement was not directly measured, an indication could be determined from the number of students that completed the activity (100%) and the high enjoyment score. Because both delivery methods included a hands-on activity and engineering students are predisposed to enjoy this type of activity, it is not surprising that both groups enjoyed the activity. A more comparative measure might be to ask participants exposed to the experimental method whether they would prefer a lecture or the storybook. It is also possible that engagement would be more a more meaningful measure for a non-technical audience.

Recalling Rowcliffe's warning that a story can be patronizing, non-scientific, and cause misinterpretation, participants' engagement scores indicate they did not feel patronized [66]. The scores on the instrument indicate there was no misinterpretation. However, in the open response for the definition of a breadboard, one student used the analogous terms in *Breadboardia* to describe a breadboard instead of the technical terms. Though this indicates the student's connection and appreciation for the story, it could reveal their inability to translate the concept. A de-briefing activity could address this concern to ensure students use technical terms.

6.5 Intercession

Instructors were available to provide support if requested throughout the activity, though the number of interventions was not measured. This would be an interesting statistic to measure in a future study, because anecdotally, there were many more intercessions required for fewer participants in the lecture group. The self-guided nature of the storybook greatly reduced the need for intervention, which could have contributed to the difference in times, as students in the lecture group waited to receive assistance. However, this does not bias the timing data as providing assistance is an expected part of any activity. Less time is required for the activity because less help is needed.

6.6 Effect of Prior Experience

The mean *total time* to complete the activity for participants with prior experience (for both the lecture and storybook groups) was faster than either mean *total time* for novice participants. This confirms the moderating effect of prior experience. There was not a significant difference in the mean time for participants with experience between the two delivery methods, because prior experience is a bigger effect than the type of reintroduction. However, the participants with prior experience who used the storybook rather than the lecture completed the activity faster, suggesting the storybook's effectiveness. The *total time* difference between participants with experience and those without was 13.0 minutes for participants in the lecture group but only 3.6 minutes for the storybook group. The step-by-step instructions diminished the *experience* effect on *total time*.

For the *total knowledge* score, assuming a valid instrument, it is interesting that the participants with experience received a 2.1% higher score ($p > 0.05$) in the lecture group compared to the storybook group, and that the reverse is true for the novice participants (0.7%). There are three possible explanations. First, the prior experience likely involved a lecture, so the reintroduction with a lecture was familiar and sparked memories. Second, the participants had prior connections to breadboards, so the ability of the storybook to connect new information to familiar concepts was not as effective as for novice participants. Third, the difference in experience level between participant groups likely contributed, as the four participants with one prior experience were in the storybook group. With a larger number of participants, the experience level could be expanded to three categories to determine whether this is the cause or whether the storybook is less effective for participants with prior experience.

For both delivery methods, the *effectiveness* scores for participants with experience were higher than the scores for the novice participants. This provides confidence in the instrument, affirms the use of time to determine ability, and validates the method used to calculate the effectiveness score.

6.7 Limitations

Type I errors are possible due to the lack of statistical significance for the *knowledge* scales. Type II errors due to the potential threats to instrument validity have been minimized by the *experience* data. However, *experience* was self-reported, which could cause either a Type I or Type II error if students overstated or understated their experience level, respectively.

Content validity is supported through the *experience* results. Additionally, the difficulty, discriminability, and distractors were evaluated for the individual knowledge variables from the instrument [69, p. 484; 75, p. 278]. There were two discriminating variables and no distractors. The difficulty of each variable ranged from 33% to 85%, with an overall average of 60%, which is reasonable.

Construct validity was addressed through a review of the instrument by external reviewers, inter-rater reliability, and blind reviews to reduce the halo effect [69, p. 210]. The lecture for the control group could have been unintentionally poorly communicated, but that too presents an advantage of the storybook: standardization of content. However, all efforts were made to ensure the slides were visually engaging and delivered with vocalized enthusiasm. Perhaps a more monotone, didactic recitation would have produced more diverse results, but that would not be fair to the students in the lecture participant group.

Internal threats such as self-selection bias and volunteer effects were minimized by using a purposive sample. Attrition effects were seen in one participant who did not complete the assessment in time. Social distancing practices ensured participants were six-feet apart to reduce the effect of communication among participants.

The small sample size can be subject to a Type II error as could be seen in the non-significant *knowledge* results (particularly in the low power scores). Additionally, the small sample size could produce a Type I error if there are biased samples, though all attempts were made to limit potential sources of bias. There were no discernable differences between the two sample groups other than the difference in group size (n = 29 and n = 43), which was necessitated by the purposive sampling methods to use existing class sections. Repeating the study would allow for a larger sample and is recommended.

7. Conclusion

If technical content can be effectively conveyed through a method that is hands-on, engaging, and different from every other class, that method should be pursued. A different modality can break up a class, shifting expectations and heightening excitement. It was shown that using the story of *Breadboardia* to learn about breadboards is engaging, faster, and conveys technical content as effectively as a lecture in a university environment. It can help students see their place in the world, build resiliency, and have fun learning through a different modality. The storybook has been reviewed for accuracy, accessibility, and clarity and has been shown to be as effective as a lecture for engineering students. Therefore, the effectiveness of a storybook can next be determined for non-technical audiences who are not pre-disposed to enjoying electronic activities, such as K–12 teachers who are technologically shy or K–12 students who have not used electronics. Additionally, the *knowledge* data collected in this study was limited to the primary technical objectives and could be expanded to include additional objectives such as retention (2a) and complementary objectives regarding components (4a–h).

This study opens the door to using a storybook as a new form of active learning in the engineering classroom instead of a lecture, as documented in the literature [1–4]. There is potential to develop a storybook for the especially didactic, dry, or difficult content in a course, incorporating a different modality to "shake up" the content and provoke interest. When unfamiliar technical information is turned into relatable characters and memorable plots, students can make connections with the content. With a deeper connection and higher engagement, students are more willing to struggle with difficult concepts. Additionally, the familiarity and nostalgia of storybooks can make difficult topics less intimidating and increase engagement. Storybooks allow for the inclusion of abstract concepts such as sustainability, civic responsibility, and the role of the engineer in society. While the findings of the study are limited to the engineering undergraduate environment, the power of the story to convey information can be universally applied.

Acknowledgments –This study was performed in accordance with the ethical standards of UPEI REB per file 6008912. An abbreviated manuscript was presented at the Canadian Engineering Education Association Conference in 2021. The funding for this project was provided by UPEI. I would like to acknowledge the contribution of three groups. First, my colleagues for their support in the development of the storybook, specifically Dr. Nadja Bressan for her review of the storybook and assistance with data collection. Second, the professional engineers and non-technical users who helped revise the storybook. Third, the editor and reviewers of IJEE for their comments and assistance refining the manuscript. Finally, if anyone would like a digital copy of the storybook to use in class, please contact the author; this storybook was created to be shared.

References

1. S. K. Sugathan and K. S. Kalid, An exploratory study of storytelling approach as an instructional tool from educators' perspective, *International Conference on Computer Technology and Development*, Malaysia, 2009, pp. 480–483, 2009.
2. G. Prayag and G. Del Chiappa, Nostalgic feelings: Motivation, positive and negative emotions, and authenticity at heritage sites, *Journal of Heritage Tourism*, pp. 1–16, 2021.
3. P. Caratozzolo, A. Delgado and S. Hosseini, Perspectives on the use of serious-storytelling for creative thinking awareness in engineering, *Multimedia Tools and Applications*, **76**(14), pp. 15707–15733, 2020.
4. C. H. Papadimitriou, MythematiCS: In praise of storytelling in the teaching of computer science and math, *SIGCSE Bull*, **35**(4), pp. 7–9, 2003.
5. Y. Hadzigeorgiou, Narrative thinking and storytelling in science education, *Imaginative Science Education*, pp. 83–119, 2016.
6. M. R. K. K. Rao, Storytelling and puzzles in a software engineering course, *Proceedings of the 39th SIGCSE Technical Symposium on Computer Science Education*, **38**(1), 2006.
7. A. E. Segall, Science fiction in the engineering classroom to help teach basic concepts and promote the profession, *Journal of Engineering Education*, **91**(4), pp. 419–423, 2002.

8. C. A. Bodnar, D. Anastasio, J. A. Enszer and D. D. Burkey, Engineers at play: Games as teaching tools for undergraduate engineering students, *Journal of Engineering Education*, **105**(1), pp. 147–200, 2016.
9. H. Woodhouse, Storytelling in university education: Emotion, teachable moments, and the value of life, *The Journal of Educational Thought/Revue de La Pensée Éducative*, **45**(3), pp. 211–238, 2011.
10. R. F. Bowman, Teaching and learning in a storytelling culture, *Clearing House*, **91**(3), pp. 97–102, 2018.
11. A. Yadav, D. Subedi, M. A. Lundeberg and C. F. Bunting, Problem-based learning: Influence on students' learning in an electrical engineering course, *Journal of Engineering Education*, **100**(2), pp. 253–280, 2011.
12. J. S. Bruner, *In search of pedagogy*, Routledge, New York, 2006.
13. A. D. Watson and G. H. Watson, Transitioning STEM to STEAM: Reformation of engineering education, *Journal for Quality and Participation*, pp. 1–4, 2013.
14. C. E. Abrahamson, Storytelling as a pedagogical tool in higher education, *Education*, **118**(3), pp. 440–451, 1998.
15. F. Banister and C. Ryan, Developing science concepts through story-telling, *School Science Review*, **83**(302), pp. 75–83, 2001.
16. K. Egan, The educated mind: How cognitive tools shape our understanding, *Canadian Journal of Education/Revue Canadienne de l Éducation*, **68**(2), 1998.
17. M. Nott, Beyond 2000: Science education for the future, *School Science Review*, **80**(291), pp. 19–24, 1998.
18. P. J. Lewis, Storytelling as research/research as storytelling, *Qualitative Inquiry*, **17**(6), pp. 505–510, 2011.
19. M. Reason and C. Heinemeyer, Storytelling, story-retelling, storyknowing: Towards a participatory practice of storytelling, *Research in Drama Education: The Journal of Applied Theatre and Performance*, **21**(4), pp. 558–573, 2016.
20. H. Y. Hong and X. Lin Siegler, How learning about scientists' struggles influences students' interest and learning in physics, *Journal of Educational Psychology*, **104**, pp. 469–484, 2012.
21. W. J. White, Optical solutions: Reception of an NSF-funded science comic book on the biology of the eye, *Technical Communication Quarterly*, **26**(2), pp. 101–115, 2017.
22. M. Wilson, Some thoughts on storytelling, science, and dealing with a post-truth world, *Storytelling, Self, Society*, **13**(1), pp. 120–137, 2017.
23. J. S. Bruner, *Actual minds, possible worlds*, Harvard University Press, Boston, MA, p. 36, 1986.
24. B. Mager, Storytelling contributes to resilience in older adults, *Activities, Adaptation and Aging*, **43**(1), pp. 23–36, 2019.
25. M. F. Astiz, Storytelling in the higher education classroom: Why it matters, *College Teaching*, **68**(4), pp. 187–188, 2020.
26. R. S. Root-Bernstein and M. Root-Bernstein, *Sparks of genius: The 13 thinking tools of the world's most creative people, Houghton Mifflin Harcourt*, Boston, MA, p. 317, 2001.
27. N. Sochacka, K. Guyotte and J. Walther, Learning together: A collaborative autoethnographic exploration of STEAM (STEM + the Arts) education, *Journal of Engineering Education*, **105**(1), pp. 15–42, 2016.
28. S. Walan, Teaching children science through storytelling combined with hands-on activities – a successful instructional strategy?, *Education 3–13*, **47**(1), pp. 34–46, 2019.
29. Z. Fang, The language demands of science reading in middle school, *International Journal of Science Education*, **28**(5), pp. 491–520, 2006.
30. G. Crocetti and B. Barr, Teaching science concepts through story: Scientific literacy is more about the journey than the destination, *Literacy Learning: The Middle Years*, **28**(3), pp. 44–52, 2002.
31. A. N. Spiegel, J. McQuillan, P. Halpin, C. Matuk and J. Diamond, Engaging teenagers with science through comics, *Research in Science Education*, **43**(6), pp. 2309–2326, 2013.
32. D. Preece and Y. Zhao, YMulti-sensory storytelling: A tool for teaching or an intervention technique?, *British Journal of Special Education*, **42**(4), pp. 429–443, 2015.
33. G. Bull, D. A. Schmidt-Crawford, M. C. McKenna and J. Cohoon, Storymaking: combining making and storytelling in a school makerspace, *Theory Into Practice*, **56**(4), pp. 271–281, 2017.
34. C. Kelleher and R. Pausch, Using storytelling to motivate programming, *Communications of the ACM*, **50**(7), pp. 58–64, 2007.
35. N. Smeda, E. Dakich and N. Sharda, The effectiveness of digital storytelling in the classrooms: A comprehensive study, *Smart Learning Environments*, **1**(6), pp. 491–492, 2014.
36. K. Geres, Resilience through storytelling in the EAL classroom, *TESL Canada Journal*, **33**(0), 2017.
37. C. Nash, *Narrative in Culture: The uses of storytelling in the sciences, philosophy and literature*, Routledge, New York, 1994.
38. N. Railton, Lessons in culture: Oral storytelling in a literature classroom, *Changing English*, **22**(1), pp. 50–59, 2015.
39. D. Fischer, Storytelling as a nursing pedagogy, *The Midwest Quarterly*, **60**(3), p. 311, 2019.
40. C. Haigh and P. Hardy, Tell me a story – A conceptual exploration of storytelling in healthcare education, *Nurse Education Today*, **31**(4), pp. 408–411, 2011.
41. M. S. Freeman and G. Burkette, Storytelling in the accounting classroom, *The Accounting Educators' Journal*, *XXIX*, pp. 29–39, 2019.
42. P. Lloyd, Storytelling and the development of discourse in the engineering design process, *Design Studies*, **21**(4), pp. 357–373, 2000.
43. A. Roncin, Rationale and teaching objectives for a Canadian engineering ethics game, *Proceedings of the Canadian Engineering Education Association*, Hamilton, ON, Canada, 2015.
44. Z. I. Sakka and I. A. Zualkernan, Digital storytelling in higher education: A case study in a civil engineering laboratory, *Fifth IEEE International Conference on Advanced Learning Technologies*, pp. 365–367, 2005.
45. J. Milton-Benoit, I. R. Grosse, C. Poli and B. P. Woolf, The Multimedia finite element modeling and analysis tutor, *Journal of Engineering Education*, **87**(S5), pp. 511–517, 1998.
46. R. Bezerra Rodrigues, Gamification in engineering education in Canada: A systematic review of the literature, *Proceedings of the Canadian Engineering Education Association*, Montréal, QC, Canada, 2020.
47. A. Trivett, An attempt to gamify a first course in thermodynamics, *ASEE Annual Conference and Exposition Proceedings*, Indiana, US, 2014.
48. B. Walsh and M. Spence, Leveraging escape room popularity to provide first-year students with an introduction to engineering information, *Proceedings of the Canadian Engineering Education Association*, Vancouver, BC, Canada, 2018.
49. T. Rice-Bailey, The Benefits of improvisational games in the TC classroom, *Technical Communication Quarterly*, **30**(1), pp. 63–76, 2021.

50. J. C. Bouwmeester, V. Komisar and A. Swarup, Using role-playing simulations to teach quality control in the design of medical devices, *Proceedings of the Canadian Engineering Education Association*, Vancouver, BC, Canada, 2018.
51. T. H. Broome and J. Peirce, The heroic engineer. *Journal of Engineering Education*, **86**(1), pp. 51–55, 1997.
52. P. Ostafichuk, C. Jaeger and J. Nakane, Development of an interactive online ethics scenario activity for engineering students, *Proceedings of the Canadian Engineering Education Association*, Montréal, QC, Canada, 2020.
53. P. Kinnear and A. Simpson, Narrative as a pedagogical approach to teaching leadership and engineering, *Proceedings of the Canadian Engineering Education Association*, Toronto, ON, Canada, 2017.
54. W. Swap, D. Leonard, M. Shields and L. Abrams, Using mentoring and storytelling to transfer knowledge in the workplace, *Journal of Management Information Systems*, **18**(1), pp. 95–114, 2001.
55. S. Secules, A. Gupta, A. Elby and E. Tanu, Supporting the narrative agency of a marginalized engineering student, *Journal of Engineering Education*, **107**(2), pp. 186–218, 2018.
56. V. Rao, G. Moore, O. A. Udekwu and B. Hartmann, Tracing stories across the design process: A study of engineering students' engagement with storytelling in an undergraduate human-centered design course, *International Journal of Engineering Education*, **36**(2), pp. 762–772, 2020.
57. D. Parkinson and L. Warwick, Stimulating thinking at the design pitch. Storytelling approach and impact, *The Design Journal*, **20**(1), pp. S4509–S4518, 2017.
58. T. Ball, L. Beckett, M. Isaacson, L. Beckett and M. Isaacson, Formulating the problem: Digital storytelling and the development of engineering process skills, *2015 IEEE Frontiers in Education Conference*, pp. 1–5, 2015.
59. H. Yu, *The other kind of funnies: Comics in technical communication*, Routledge, New York, p. 20, 2016.
60. N. Shamsuddin and J. Kaur, Students' learning style and its effect on blended learning, does it matter?, *International Journal of Evaluation and Research in Education*, **9**(1), pp. 195–202, 2020.
61. M. R. Emami, M. C. F. Bazzocchi and H. Hakima, Engineering design pedagogy: A performance analysis, *International Journal of Technology and Design Education*, **30**(3), pp. 553–585, 2020.
62. N. Othman and M. H. Amiruddin, Different perspectives of learning styles from VARK model, *International Conference on Learner Diversity*, Bangi, Malaysia, pp. 652–660, 2010.
63. National Research Council *How people learn: Brain, mind, experience, and school: Expanded edition*, The National Academies Press, Washington DC, pp. 12–14, 2000.
64. M. Prince, Does active learning work? A review of the research, *Journal of Engineering Education*, **93**(3), pp. 223–231, 2004.
65. A. Yadav, D. Subedi, M. A. Lundeberg and C. F. Bunting, Problem-based learning: Influence on students' learning in an electrical engineering course, *Journal of Engineering Education* **100**(2), pp. 253–280, 2011.
66. S. Rowcliffe, Storytelling in science, *School Science Review*, **86**(314), pp. 121–126, 2004.
67. S. Bolkan, Storytelling in the classroom: Facilitating cognitive interest by promoting attention, structure, and meaningfulness, *Communication Reports*, **34**(1), pp. 1–13, 2021.
68. Accreditation Board for Engineering and Technology, *Criteria for Accrediting Engineering Programs*, ABET, p. 5, 2020.
69. L. Cohen, L. Manion and K. Morrison, *Research methods in education*, Routledge, New York, pp. 140, 210, 484–485, 618, and 654, 2011.
70. B. L. Gleason, M. J. Peeters, B. H. Resman-Targoff, S. Karr and S. McBane, An active-learning strategies primer for achieving ability-based educational outcomes, *American Journal of Pharmaceutical Education*, **75**(9), pp. 186–186, 2011.
71. M. Tavakol, and R. Dennick, Making sense of Cronbach's alpha, *International Journal of Medical Education*, **2011**(2), pp. 53–55, 2011.
72. Engineers Canada, *Canadian engineers for tomorrow*, Engineers Canada, 2017.
73. W. E. Martin and K. D. Bridgmon, *Quantitative and statistical research methods: From hypothesis to results*, Jossey-Bass: San Francisco, CA, p. 113, 2012.
74. JASP Team, *JASP* (0.14.1) [Computer software], Accessed 2020.
75. W. P. Vogt, *Quantitative research methods for professionals*, Pearson, Boston, MA, p. 278, 2007.

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