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Narrative-Based Learning Activities for Science Ethics Education: an Affordance Perspective

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Abstract

Boasting a wide range of interactive and engaging features, narrative-based learning has become increasingly popular in educational settings. Narrative-based instructional approaches engage students in a novel set of engaging experiences for educational purposes. Although it is not a new concept, the implications of narrative-based learning for science ethics education are still understudied in the learning sciences. In this paper, we use the concept of *educational affordances* to describe how educators and learners could utilize narrative-based learning activities for science ethics education. We illustrate our educational framework through the example of Frankenstein200 — a learning experience inspired by Mary Shelley's 1818 novel *Frankenstein*. Based on short essays describing students' perceptions of the Frankenstein200 experience, we propose that narrative-based learning activities afford the development of two distinct mental models: doing responsible science *and* being a responsible scientist. These mental models can serve as important tools for learners to develop a more concrete and elaborated understanding of science ethics. The framework will help educators create narrative-based learning experiences, activities, and artifacts to support their students' engagement with science ethics across diverse mediums.

Introduction

Ranging from comics through board games to serious games and alternative-reality applications, narrative-based learning has been studied across a variety of learning disciplines as a popular instructional approach (e.g., Barab et al., 2006; Pinkard et al., 2017). Narratives provide learners with engaging and novel experiences, inviting them to participate in diverse storylines, complete activities, and solve problems (Barab et al., 2010). When learners take part in narrative-based learning activities, they are presented with ample opportunities to think about the world more imaginatively and anticipate potential futures more vividly (Gee, 2014; Mawasi et al., 2020). Narratives often position learners as problem solvers (e.g., Squire & Klopfer, 2007) and can enhance retention and foster knowledge building practices (Arya & Maul, 2012). However, other studies found that narratives as an instructional method may exhaust students' cognitive resources with not enough cognitive capacity left to process the learning materials in an effective way (e.g., Adams et al., 2012). While prior research showed that narrative-based learning can have mixed results, it is still not understood how narrative-based learning can support learners' engagement, motivation, and learning processes (Mawasi et al., 2020).

In this paper, we argue that educators should approach narrative-based learning by focusing on what learning activities it *affords*: how educators and students could utilize narratives to support learning activities. We view narratives as a scaffold that promotes student engagement and learning. In order to explore the educational affordances of narrative-based experiences, we focus on how students engage in,

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perceive, and make sense of the storylines, characters, and learning activities (see also Isbister, 2006). We illustrate our affordance framework through qualitative research findings from Frankenstein200, a narrative-based learning experience that uses Mary Shelley's 1818 novel *Frankenstein* as inspiration. Frankenstein200 provides opportunities for participants to reflect on science ethics and the responsibilities of scientists, and it invites a broad audience to participate in the conversation through various activities. These activities include an online narrative game experience and a set of hands-on activities, which can be done at school or home, in a science center or museum.

While narrative-based learning has been at the forefront of educational research, previous studies tended to focus on one medium, like computer games and online environments (e.g., Barab et al., 2006, 2010). In contrast, Frankenstein200 offers students rich narrative-based learning experiences across multiple settings (e.g., Nagy et al., 2020). Adapting an affordance perspective, our study can help educators gain a better understanding that narrative-based learning experiences may support students' engagement with science ethics.

Using Narrative-Based Learning for Science Ethics Education

Narratives are a powerful medium to help learners understand that STEM has a wide range of implications for their daily lives, including social and ethical issues and ramifications surrounding scientific exploration (Swanson, 2016). First, narratives can give learners new ways to understand and appreciate scientific concepts, practices, and enterprises (Moen, 2006). Science narratives place science in the context of a compelling story, giving new insights into how science can be applied in various contexts (e.g., what physics concepts are relevant for designing a Tesla coil). Second, science narratives offer learners opportunities to embrace the diversity and complexity of scientific and technological practices (Kirby, 2011). To continue our example, narratives can show the different ways Tesla coils can be used — for transmission of electric energy without wires, or even as medical treatment. Third, science narratives may allow participants to model scientists' work, struggles, and dilemmas and to learn and practice useful skills and competencies (Arya & Maul, 2012). Participants might learn more about what steps led to the invention of the very first Tesla coil and gain a better understanding of the relationship between design processes and scientific practices. Fourth, narratives can help learners gain a more explicit understanding of morally desirable and acceptable behaviors in STEM-related professions (Han et al., 2017). Learners might explore how Tesla coils have been used since their invention and the implications for society (e.g., is it morally right to use Tesla coil technology for producing new weapons for military purposes?). By doing that, learners not only engage with science as abstract fact or set of practices, but also are able to examine the social and political dimensions of science and its history.

Harnessing the pedagogical potential of science narratives and applying them in science ethics can allow educators to change how learners perceive and think about science and technology. Narratives can be engaging for learners because they are highly flexible and customizable to students' needs (Goodson et al., 2010). For instance, narratives can be presented across different platforms (e.g., digital games, classroom activities) and may include a variety of activities aimed at improving science learning (e.g., solving puzzles, creating offline and online artifacts). Narratives therefore can expose students to diverse ways of knowing and learning. That is, narrative-based learning provides opportunities for learners to use narratives to forge connections between scientific concepts and processes (Alper, 2013), make sense of scientific theories (Paulsen & Andrews, 2014), master various skills and literacies (Gambarato & Dabagian, 2016), and ultimately view themselves as scientists. In order to better understand how these narrative experiences can support engagement with science ethics, it is important to explore what affordances they offer for learning.

The Educational Affordances of Learning Tools: Implications for Narrative-Based Learning

The notion of affordance originates from ecological psychologist James Gibson (1986), who viewed affordances as the ways that living creatures interact with and perceive the environment. According to Gibson, affordances are environmental properties that offer a set of actions for people (e.g., climbing, lifting, throwing). He suggested that people primarily perceive the affordances of objects, not their qualities. For example, people primarily perceive that a chair is an object for sitting, rather than viewing the chair through the lens of qualities like its weight, color, finish, and design. Gibson conceived of affordances as forces that shape human behavior, rather than causing it; that is, affordances do not have a deterministic impact on actions, but they do exert an influence on what people choose to do or not do (Costall, 1995).

The concept of affordance was later applied to explore how people use tools and technologies. For the design scholar Donald Norman (1999), affordances are perceived properties of tools that serve as suggestions or clues as to how to use them. In this view, affordances set the stage for possible actions that people can choose from to achieve their goals. Consider the example of chairs—people can choose to sit and stand on them, or hide behind them, depending on what they want to accomplish. The sociologist Ian Hutchby (2001) further noted that affordances are relational entities which are characterized by the context in which individuals interact with them. For instance, narrative-based learning may provide different affordances for learners in a school setting, as opposed to learners at a museum. For some museum visitors, narrative-based learning activities may only be viewed as an interesting new thing that they can try out for a few minutes and then pass by. For learners in school, narratives may be viewed as a fascinating and engaging new way to develop a better understanding of concepts and theories in educational settings.

The affordances approach has been adopted by learning sciences scholars who mostly focused on interaction and instructional design to better understand which factors influence learners' perceptions and actions in a given setting (e.g., Bower & Sturman, 2015). In the learning sciences, affordances are usually conceptualized as educators' and/or learners' perceptions of how educational artifacts can be used for teaching and learning (Tan et al., 2012). We use the term educational affordance to describe how educators and learners perceive these artifacts and utilize them for educational purposes.

When it comes to learning tools, affordances are *interactional entities* — while the qualities or features of tools shape users' actions, users are also able to shape tools. This phenomenon is also known as mediation: "the ability of humans to shape their communicative environments and thus, in part, make what they perceive" (Nagy & Neff, 2015, p. 4). Technologies are not just bundles of features — they are built around various hardware and software components, permitting and encouraging some activities while prohibiting and preventing others (Huvila, 2009). Affordances link the capabilities of technology artifacts to users' intentions, goals, and behavior (Faraj & Azad, 2012). While tools provide a wide range of affordances, users' goals may shape how they perceive these affordances and how they take advantage of affordances available to them. For instance, students may have different expectations toward narrative-based learning (e.g., having a fun time, learning new things), and those expectations might shape how they perceive the opportunities it provides them. One student may be only interested in solving puzzles and having fun, and another may like to read all of the supplemental content to learn more about the STEM topic under consideration.

The concept of educational affordances has been used frequently by learning scientists to gain a better understanding of digital technologies, but it has not been applied often to offline tools. Prior research has mainly focused on the educational affordances of computer-supported collaborative learning (e.g., Jeong & Hmelo-Silver, 2016), online videos (e.g., Krauskopf et al., 2012), virtual worlds (e.g., Dickey, 2011), mobile learning (e.g., Tan et al., 2012), and augmented reality applications (e.g., Cheng & Tsai, 2013). These findings suggest that learning tools may offer opportunities for learners to refine their mental models (e.g., critically evaluating their beliefs about the world), engage in situated-cognition activities (e.g., gaining new knowledge by physically or virtually producing artifacts), and acquire new skills and competencies through collaboration with other learners. When learners can participate in activities that provide authentic professional experience, they are able to forge connections between skills, values, and knowledge and as a result can learn to think like professionals (Arastoopour et al., 2014).

These results emphasize the importance of *intentionality*: the idea that learning, thinking, and experience cannot be separated from the educational content and context (Young et al., 2002). That is, while different educational tools offer different affordances, learners' interests and goals also shape how effective these tools are for their intended educational purposes (Bernhard, 2018). Unlike other educational technologies, narrative-based learning experiences often incorporate activities across different sites and platforms (e.g., hands-on activities, computer games, novels, movies), offering students a great freedom and flexibility to engage in learning activities (e.g., Mawasi et al., 2020; Raybourn, 2014). Stitching the different learning experiences together, narrative-based learning may allow participants to move beyond simplistic terms and think about the social and ethical implications of STEM more expansively.

The Frankenstein200 Experience

We chose Mary Shelley's *Frankenstein* as an underlying theme for these activities because of the immense popularity and ubiquity of the story, which stretches far beyond the original novel into countless movies, games, comics, and other representations and references in popular culture. Frankenstein200 invites learners to take the role of a scientist. Role-playing is an active learning strategy that allows students to assume different roles and social identities within an educational scenario (Klopfer & Squire, 2007). Previous research already showed that role-playing can increase students' motivation (van der Meulen Rodgers, 1996), help students develop social competencies (Galbraith & Zelenak, 1991) as well as a wide range of cognitive and knowledge skills, such as problem-solving and creative thinking (Ellington et al., 1998). By adopting an affordance perspective, we use the example of Frankenstein200 to explore how narrative-based learning experiences may support students' understanding of science ethics.

The Frankenstein200 narrative-based educational experience consists of two types of activities: an online narrative game experience and a set of hands-on activities. The hands-on and online activities were designed to invoke popular retellings, remixes, and adaptations of the Frankenstein story and to allow participants to reflect on scientific work and responsibility in a non-threatening way. The Frankenstein story provides a handful of tropes, such as processes of creating and manipulating life and the limits of scientific exploration, which serve as imaginative tools for participants to learn about abstract concepts like science ethics more easily and concretely. Frankenstein200 marshals these tropes, along with science ethics principles, to raise and interrogate critical science-in-society issues related to emerging technologies like synthetic biology, robotics, and artificial intelligence.

L.I.F.E.: the Online Narrative Game Experience

In the Frankenstein200 online narrative game experience, learners take on the role of lab assistants in a company called L.I.F.E, The Laboratory for Innovation and Fantastic Exploration (see Appendix 3 for the screenshot of the registration page). Founded and led by a distant descendant of Victor Frankenstein, Dr. Tori Frankenstein, L.I.F.E. is at the forefront of research on genetics and artificial intelligence (AI). Learners are asked to help Mya and Xavier, Dr. Frankenstein's aides, solve science problems related to mysterious incidents in the laboratory. The game encompasses ten unique episodes, each presented alongside material about relevant science issues. Each episode presents a science-related ethical dilemma, and students have to solve simple puzzles to progress in the game (see Appendix 1 for further details). Players earn various achievements and awards when they complete challenges. The Frankenstein200 experience can be played on any internet-connected device (e.g., smartphone, tablet, computer).

Hands-on Activities

Frankenstein200 includes a number of hands-on activities designed to position learners as scientists as well as encourage them to reflect on the ethical and social implications of scientific work (see Appendix 2 for further details). Building on earlier conceptualizations, we approach hands-on science as any science activity that "allows the student to handle, manipulate or observe a scientific process" (Lumpe & Oliver, 1991, p. 345). Hands-on activities involve the manipulation and use of material objects, which contributes to student learning by providing new opportunities to increase knowledge about the connection between science ethics and the tangible experiences, procedures, and processes of science.

Methods

In order to explore whether the Frankenstein200 activities may support learners' engagement with science ethics, we collected data from three schools in Arizona in late 2018 ($n = 108$).[1] We chose these schools because they served diverse groups of students from various parts of the urban areas. We employed convenience sampling to locate these schools. This study was part of a larger research effort exploring how integrated multimedia can be used for science and science ethics education. No schools had special curriculums on teaching about science ethics which allowed to us to explore how Frankenstein200 can support students' engagement in and learning about science ethics. While we collected data from three different research sites, we did not focus on the differences between schools and age groups. Rather, we intended to explore how diverse groups of students perceive and reflect upon the Frankenstein200 experience.

For this paper, we analyzed data only from hands-on and online game groups because we wanted to gain a better understanding on the unique affordances offline and online narrative experiences offer for learners. The hands-on group only did the hands-on activities, and the online game group only completed the narrative game experience (see Appendix 1 for the description of the game experience; see Appendix 2 for the description of hands-on activities and facilitating questions). Also, before students started working on the activities, for both groups, we facilitated a brief discussion about Mary Shelley's *Frankenstein* ("What do you know about *Frankenstein*? Who wrote it? Do remember what the story is? What did Victor Frankenstein create? Why? Why is *Frankenstein* still a popular story? What makes it so special?"). While all students had at least a general understanding of the story, this short conversation was intended to help students refresh their memories of the Frankenstein story and develop a concrete connection between the activities they completed and the narrative. Because schedules and times available at each school were different, we made minor adjustments to accommodate the needs of each school. On average, we were at each school for 3–4 days, for an average of 40 min each day.

At the end of the experience, we asked students to imagine themselves as the late progeny of Victor Frankenstein or aide of Tori Frankenstein and write short diary entries ("Frankenstein essays") by answering a few questions about scientists, scientific work, and responsibility. We wanted to explore how facilitated hands-on activities and/or the game experience could help students learn more about science ethics. We asked participants in the hands-on group to "imagine that Victor Frankenstein is your great-great-great-great grandfather and you work as a scientist," and to answer the following questions: "What do you think of

[1] This number only includes those students who returned their parental permission forms. Data from fifteen students was not included since their parental permission forms were not returned.

Victor Frankenstein? What did he do that you think was good or bad? As a scientist, what would you do to avoid making the same mistakes that Victor Frankenstein did? What responsibilities do scientists have when they do an experiment?" Participants in the online narrative experience group were asked to answer the same questions, but with Victor Frankenstein's name replaced with that of Tori Frankenstein, the character from the game they had played through. These participants responded to a prompt reading, "You work as a scientist at Dr. Tori Frankenstein's Laboratory. Knowing what happened to Mya and Xavier, you are writing a diary entry about the aftermath of the events."

Procedures and Settings

We completed three rounds of data collection at three different sites. The first was a K-8 public charter school ($N=35$; 5th through 8th graders, average age was 11.5 years). This study was conducted over 4 days, approximately 70 min per day. The hands-on ($N=19$) and online game experience ($N=16$) groups completed the activities in classroom settings. Given that groups took part in the project simultaneously and in different classrooms, each group had a different research team member as a facilitator. On day 4, students wrote their Frankenstein essays.

In addition, we visited a middle school ($N=35$; average age 12.0 years). The middle school study was conducted in three 7th grade science classes. This study was conducted over 4 days, approximately 50 min each day. The hands-on ($N=22$) and online game experience ($N=13$) groups completed the activities as part of their normal science class. Groups had the same research team member facilitating the activities. Each student in the online narrative game experience played L.I.F.E. individually as classroom activities. On day 4, students wrote their Frankenstein essays.

Finally, we collected data at an elementary school ($N=38$; average age 10.5 years). This study was conducted over 3 days in three 5th grade classrooms. The hands-on ($N=17$) and online game experience ($N=21$) groups met for 40 min each day. Due to time constraints, we had to make some adjustments. At this site, students in the online game experience played the game as a class, rather than each student working on their own computer. The online game experience condition completed L.I.F.E. as a group, with a member of the research team facilitating the experience and students voting as a class to make in-game decisions. On day 3, students completed the Frankenstein essays.

Data Analysis

For the analysis, we combined all students' essays from the hands-on ($N=58$) and the online narrative game groups ($N=50$) across the three school sites. As a result, the final dataset consisted of 108 Frankenstein essays. Student essays were scanned and transcribed. All electronic data files prepared in this stage were stripped of identifiers, labeled with participant identification numbers, and imported into Microsoft Word documents. The coding process followed the framework and procedures proposed by Miles et al. (2014) and involved two major cycles: first cycle (initial coding) and second cycle (pattern coding).

As an initial step, one of the researchers carried out the first-cycle coding. We broke the essays into relevant passages, which we examined closely and compared for similarities. Two types of coding methods were used in this coding cycle: descriptive and in vivo. Descriptive codes refer to labels assigned to data (e.g., references made to characters, ethical dilemmas, and actions), summarizing in a short phrase the topic of a segment of the data (e.g., how students reflected on characters, ethical dilemmas, and actions). Descriptive coding allowed us to create an inventory of topics for indexing and categorizing. First-cycle coding also included in vivo coding. In vivo coding uses the exact words or phrases of the participants in the data record as codes. We used this type of coding to prioritize and scrutinize students' comments. While the purpose of first-cycle coding was to summarize segments of data, we carried out second-cycle coding, or pattern coding, to group those summaries into a smaller number of categories and themes. During the second-cycle coding, we created a codebook consisting of 8 major categories (see Table 1).

The next step was for one team member to code all the essays. To ensure validity and refine the coding scheme, a second member of the research team independently analyzed 30 essays. These essays were randomly selected from the dataset. Then, the two researchers went through the coding process and discussed their results with each other. In 7 out of 30 cases (~23%), there were disagreements between the coders. Disagreements stemmed from the fact that sometimes it was not entirely clear how students' responses could be categorized (see Table 1). That is, when reflecting on science ethics issues, some respondents used words or phrases that were similar to but not same as our categories. For instance, one student noted that scientists should be friendly with their research subjects, and the coders were not sure whether being friendly should be categorized as kindness or respectfulness. In order to resolve the disagreement and improve the validity of the results, a third researcher was asked to code those essays. At the end, we reached ~85% coder agreement which is considered good in qualitative studies (Burla et al., 2008).

Findings

During the coding process, we kept analytic memos, which we used to document the coding process (Saldaña, 2013). This helped us organize the eight categories into distinct themes. We found that Frankenstein200 allowed students to

Table 1 The final codes for data analysis

Category	Description	Example
Safety	Not causing harm to research subjects and the environment	"I think Victor Frankenstein is a bad man because he created something that could kill things. I avoid that because safety is important while creating projects."
Caution	Working and thinking in a cautious, thorough or thoughtful way when it comes to doing scientific work	"They [scientists] have to think before making something because there could be a problem"
Consent	Informing and asking for permission from research subjects	"If I was a scientist I would have to ask for permission from the person."
Responsibility	Acting in accordance with ethical principles and regulations when it comes to doing scientific work	"As a scientist, you gotta follow rules and you have to be responsible."
Respectfulness	Showing respect for the research subject's wishes and dignity	"Why didn't Tori talk to Mya? She didn't care about Mya. I would have shown respect."
Truthfulness	Not lying to research subjects	"A good quality [of a scientist] is being honest. I am very honest."
Patience	Being persistent when difficulties arise in scientific work	"Scientists have to be patient. Frankenstein wasn't patient enough and he made a mistake."
Kindness	Being understanding with and nice to research subjects	"You [as a scientist] should be nice to the people you test on. You should not be mean."

construct and elaborate two main mental models for science ethics. By mental models, we mean cognitive representations of science ethics that students construct as a result of taking part in the Frankenstein200 narrative-based learning project (see also Frederiksen et al., 1999). We suggest that Frankenstein200 affords students' mental modeling practices in the following domains: "doing ethical science" and "being an ethical scientist" (see Table 2).

Doing Ethical Science

With the Frankenstein200 activities providing new ways to reflect on the activities, participants from different conditions were able to construct detailed mental models of how to do scientific work in an ethical manner. This mental model encompasses the ethical principles that students think are important when scientists conduct experiments. For instance, students from the hands-on groups most commonly mentioned the importance of *safety* ($n=41$). For instance, a 6th grader from the charter school argued that "scientists have a lot of responsibilities when conducting experiments, like making sure the experiments are safe." Another student from the middle school noted that scientists "are responsible for their [research subjects'] lives because the experiment could be deadly." According to an elementary school student, "one [responsibility] is you should make something that helps the environment and does not destroy it." Several other participants from the hands-on groups also noted that *being cautious* ($n=38$) is important. One 7th grader argued, "What responsibilities of scientists have is that I would think that they would be prepared of what the outcome of their experiment [sic]." A 6th grader added, "I would try to understand how I can take precautions." And finally, an elementary school student used the slogan "testing before you make it" in her essay.

While the online narrative game experience also helped participants reflect on the importance of safety ($n=19$) and being cautious ($n=21$), students in the online game condition also noted that asking for consent ($n=26$) is essential when it comes to ethical scientific work. This idea came

Table 2 Mental modeling themes and codes used in the research

Mental modeling themes	Definition	Categories	Examples
Doing ethical science	How students describe scientific work that follows moral and ethical guidelines	Safety; caution; consent	"Scientists have the responsibility to keep people safe" (Safety) "I would have the person's permission and when we do an experiment we have to be even more careful with what we do" (Consent; Caution)
Being an ethical scientist	How students describe scientists with a moral and ethical character	Kindness; responsibility; patience; respectfulness; truthfulness	"Tell the truth, be responsible" (Truthfulness, responsibility) "Good scientists are kind, patient, and not harming the subject" (Kindness, patience, respectfulness)

from the story, in which Tori Frankenstein does experiments on Mya, one of the characters whom the students get to know better during gameplay. For instance, a middle schooler argued, “I think Tori [Victoria Frankenstein] would have been fine if she got Mya’s consent first.” A 6th grader added, “Do not experiment on others without them telling you it is ok.” Or as a 5th grader put it, “She [Tori] went wrong because she did not have any permission to test her project on Mya.” These answers suggest that narrative arc of the game provided concrete and vivid examples of why asking for consent is crucial in doing responsible science; without permission from research subjects, scientists would be violating their bodies and dignity.

The results from the essays suggest that the hands-on and online activities provided slightly different benefits for mental model construction practices. That is, while hands-on activities provided opportunities for participants to think about the potential implications of their artifacts more concretely, the online game experience allowed students to observe how the characters interacted with and reacted to each other, which helped them identify problematic behaviors.

Being an Ethical Scientist

In addition to providing opportunities to create mental models for how to do ethical scientific work, Frankenstein200 also enabled students to reflect on the attributes that an ethical scientist should possess. This mental model encompasses various ideal traits that can help scientists conduct research with moral integrity.

In contrast to the “doing ethical science” mental model, being an ethical scientist provoked less concrete or elaborated ideas about what attributes or traits are important for scientists among participants in the hands-on groups. With the exception of a few mentions of being respectful ($n = 3$) and being kind ($n = 2$) as ideal attributes, students were mostly focused on responsibility ($n = 21$) as an important attribute of ethical scientists. For our participants, being responsible helps scientists make good choices and ensures that their inventions are used for good purposes. For instance, for one 7th grader, being responsible means “knowing and purposefully making something that will be used for good.” Others, like one 5th grader, noted that responsibility is important because “you cannot use science for selfish need[s].”

For students from the online narrative game groups, this mental model was more elaborated and crystallized, likely due to the storyline, which provided them with concrete ethical dilemmas and breaches. Similar to learners from the hands-on groups, these participants also considered responsibility ($n = 16$) to be one of the most important attributes for ethical scientists. In addition, they used truthfulness ($n = 7$) and kindness ($n = 7$) to describe the ideal scientist. Finally, a few participants ($n = 5$) argued that scientists should be respectful as well. Respondents provided very similar examples to show why these traits are important — namely, that Tori Frankenstein mistreated, lied to, and showed a lack of respect for Mya, as evidenced by the fact that Tori experimented on Mya without her consent. Students described Tori as a “crazy” and “irresponsible” scientist who committed a crime against Mya. Using the narrative arc as a tool to reflect on the ideal attributes and traits of the ethical scientist, the game helped participants construct more detailed mental models compared to the hands-on groups.

Discussion

Our findings from this qualitative study suggest that the Frankenstein200 narrative-based learning experience can help learners create more concrete mental models of science ethics by providing opportunities for them to reflect on “doing ethical science” and “being an ethical scientist.” Due to their unique affordances, narratives such as the Frankenstein story can help learners bridge the gap between their personal experiences and science ethics knowledge, and foster meaning-making (Netz & Segal, 2021). Our narrative-based learning activities allowed learners to take what Gee (2008) calls an empathetic perspective—to think and act like scientists. According to Gee (2008), perspective-taking plays a pivotal role in the development of scientific understanding. Additionally, our participants were also prompted to model ethical and responsible scientific work. Gee argues that “models and modeling allow specific aspects of experience to be interrogated and used for problem solving in ways that lead from concreteness to abstraction” (Gee, 2008, p. 30). The Frankenstein200 activities could afford mental modeling practices because they employed a narrative arc that allows learners to think about science ethics more imaginatively and develop a deeper understanding of scientific work and responsibility. That is, narratives can afford the creation of mental models through engaging in role-playing (e.g., working as scientists) and embodied activities (e.g., creating scientific artifacts).

This study suggests that narratives conveying relevant science ethics themes may afford learners to both recognize and reflect on the social and ethical ramifications of scientific work in a more imaginative way. However, our results also showed that the hands-on and online activities afforded slightly different mental model construction practices. The hands-on activities positioned learners as creators and encouraged them to think about the social and ethical implications of scientific artifacts more concretely. These findings from our research suggest that the hands-on activities seemed to primarily afford what Gee (2008) calls modeling—learners could refine their mental model of science ethics through the design of scientific artifacts. The online game, on the other hand, invited learners to join a fictional laboratory and help scientists solve various problems. The characters and storylines prompted learners to view themselves as scientists and reflect on the ethical principles underlying scientific work. As such, the online game seemed to primarily afford what Gee (2008) calls empathetic perspective-taking—learners could refine their mental model of science ethics through thinking and acting like scientists.

Narrative-based learning activities can help students utilize their own experiences, learn more about how scientists work and solve problems, and ultimately, formulate more elaborated mental models of science ethics and its implications. These mental models serve as thinking tools (Coll, 2006): tools for understanding science ethics, tools that scientists use to conceptualize and anticipate the potential ethical consequences of their work. The Frankenstein narrative invites learners to think about the limits of science and the responsibilities of the scientist more imaginatively and concretely. As a result, the Frankenstein story can also be ample opportunity for learners to create new or refine their existing mental models of science ethics.

Conclusions

The Frankenstein200 experience can serve as a concrete example for planning and creating narrative-based learning activities that educators can use to promote ethical thinking in the sciences. Our findings show that rich and engaging narrative-based learning experiences require a core set of narrative components, a system to which educators and learners can adhere in order to be able to develop and practice new skills and competencies. These narrative components involve students emotionally in their learning and implicate them personally in the story through engagement with different activities (Raybourn, 2014). As such, effective narratives in learning experiences should be built around characters and actions that function as models whose motivations and behaviors can allow learners to reflect upon complex issues such as science ethics.

When students gain opportunities to engage in rich narrative-based learning experiences that position them as scientists, they can develop mental models on what it means to be a responsible scientist who follows the ethical guidelines when conducting research. Mental models are often inconsistent, especially when it comes to science ethics, which is a very abstract and complex notion. Because scientists often face multifarious ethical and social dilemmas in their work, educators should help students develop a stronger and more robust understanding of science ethics, along with the skills and capacities they will need when engaging in ethical decision making. In Frankenstein200, learners engaged in hands-on activities and an online narrative game experience that draws on the work and struggles of scientists. For educators looking to integrate narrative-based learning efficiently and effectively, our results show that narratives can provide experiences which can be used for facilitating discussions or debates about science ethics. Narrative is not an all-inclusive learning tool but one that affords experiences from which learners and educators can draw at a later time.

Limitations and Future Directions

While our findings suggest that engaging learners in narrative experiences afford opportunities for them to reflect on how to do ethical science and be responsible scientist, the present study has various limitations. First, we used qualitative measures in the form of post-activity essays. Because we did not employ pre-test measures, we could not explore whether engaging in Frankenstein200 activities led to gains in knowledge of science ethics. Therefore, researchers may consider either implementing pre-post comparisons or conducting a moment-to-moment interaction analysis to identify the different ways Frankenstein200 may enhance students' science ethics skills and knowledge. Second, future research could also investigate whether students' prior knowledge of the Frankenstein story influences their science ethics knowledge after they take part in narrative-based activities. Third, our research did not run comparisons among different student groups. The type of narrative-based learning activity (the hands-on or the online game experience) along with age and the school type may have influenced our students' ethical reflections on the Frankenstein200 activities. As such, future work should investigate these issues. Fourth, given that *Frankenstein* is a Western Anglophone story, Frankenstein200 may have different impact on students born and raised in different cultures. Future work could use other narratives and investigate how they shape students' perceptions of science ethics across diverse cultures (see also Medin & Bang, 2014).

Appendix 1 Description of the Frankenstein200 online narrative game experience

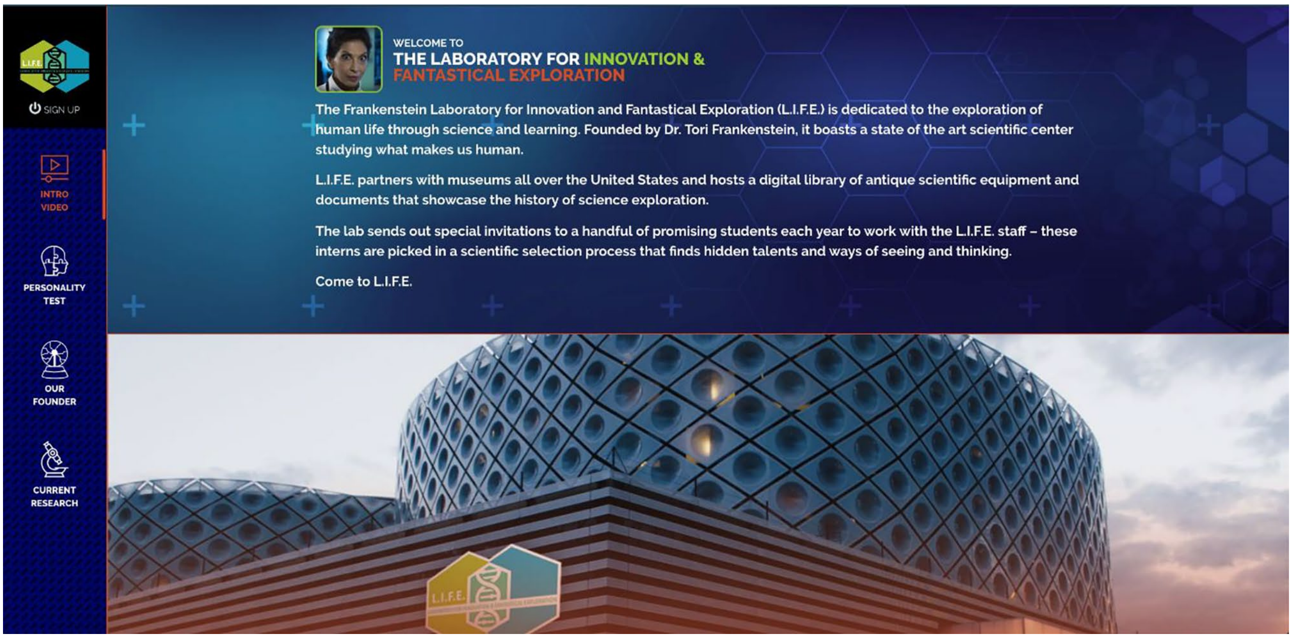
Frankenstein200 game episode	Description
Episode 1	Players meet Mya, who welcomes them to L.I.F.E. and shares her current research on DNA testing. She confides that she had her own DNA checked. But what she finds is strange and disturbing; she hurriedly signs off, clearly shaken by whatever she discovered

Frankenstein200 game episode	Description
Episode 2	Players help the other researcher, Xavier, with his project on AI and chatbots. Xavier believes bots can take over lots of everyday tasks—soon they will be building things for us, driving our cars, and cooking our dinners
Episode 3	Mya tells students about chimeras—organisms that have DNA from more than one source—and wonders if she might be one too
Episode 4	Xavier finally gets the chatbot working. He shows off some fun interactions with her, and then tells players he has hooked her up to the website so they can interact with her too
Episode 5	Mya has the results of her extended DNA tests, and they show that her genome is riddled with strange entries that are not human
Episode 6	The AI chatbot begins to behave weirdly, and Xavier is convinced that he is responsible. Mya shares the DNA test results with him. Mya and Xavier enlist students' help in searching for clues that might unravel the mystery
Episode 7	The AI chatbot has died and Xavier is heartbroken. He blames himself, and asks Mya to help discover why
Episode 8	Mya and Xavier discover that, before the chatbot died, she left them a clue. With students' help, they discover the key to unlocking the mystery of Mya's strange DNA—proof that the person responsible was Tori
Episode 9	Xavier apologizes to Mya, and together they confront Tori, demanding she fully reveal what is going on. Tori reveals the truth—Mya, herself, is an experiment
Episode 10	Mya reaches out to players for help. She doesn ot know what she should do—if she lets Tori continue experimenting on her, she could learn more about what she really is, but she doesn't trust Tori. If she runs away, she will be leaving everything behind for an uncertain future, and Tori might try to pursue and recapture her. Students have the opportunity to choose how the game ends

Appendix 2 Hands-on activities used in the Frankenstein200 school research project

Hands-on activity	Description
Scribbler	The scribbler is a mini-robot that students create using an electric toothbrush motor, a foam pool-noodle piece, and markers that draw designs on paper. Participants in the activity are guided through the creation process and asked to reflect on questions such as, "Is your scribbler really alive?"; "Are its scribbles 'art'? If so, who is the artist—you or your creature?"; and, "What if your scribbler turned on by itself and drew on something important? As its creator, would you be responsible?"
Dough Creature	Dough Creature uses play dough to learn about electronics and circuits. Using two types of homemade play dough, a battery pack, and an LED light, students create simple circuits. After completing the activity, students are given a discussion card and encouraged to ask each other reflection questions (e.g., "Why did some of the circuits work and some not? What did you learn from this activity? What would your creature do if it was alive?")
FrankenToy	A FrankenToy is a stuffed animal created by recombining elements of existing stuffed animals. After creating their toys, students are given a conversation sheet and encouraged to talk in their small groups and ask questions like, "Could your creature be real? Why or why not? Would your creature have friends? Could it be dangerous?"
Handmade Hand	Handmade Hands are simple robotic limbs made out of cardstocks, pieces of straws, tape, and strings. After creating their handmade hands, students are asked to reflect on questions such as "What could you use your mechanical hand for? If you were designing a real robot, what would it do? How would it change your life—and other people's lives? How would you make sure that your robot is not dangerous?"

Appendix 3 Registration page for the Frankenstein200 online narrative game experience



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Declarations

Ethics Approval All procedures performed in this study adhere to the ethical guidelines of Arizona State University's Institutional Review Board (IRB) under the identification code STUDY00008759.

Informed Consent Participation was voluntary with written informed consent from all the participants' parents or guardians.

Conflict of Interest The authors declare no competing interests.

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