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EDITED BY
Christoph Kulgemeyer,
University of Bremen, Germany

REVIEWED BY
Carla Morais,
University of Porto, Portugal
Valerie Harlow Shinas,
Lesley University, United States

*CORRESPONDENCE
John Voiklis
johnv@knology.org

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Science through storytelling or storytelling about science? Identifying cognitive task demands and expert strategies in cross-curricular STEM education

Jena Barchas-Lichtenstein[1], Melina Sherman[1], John Voiklis[1]* and Leah Clapman[2]

[1]Knology, New York, NY, United States, [2]PBS NewsHour Student Reporting Labs, Washington, DC, United States

While recent shifts away from sharply demarcated disciplines to cross-curricular K-12 education show great promise for enhancing students' interest and the relevance of subject matter, there remain many challenges to implementation as envisioned, not least among them teacher education. Most current teachers are socialized into disciplinary norms and identities through their pre-service education. To advance cross-curricular teaching, then, teachers need support, including more attention to the instructional design of teacher-facing materials. Without attention to teachers as learners, teachers will continue to implement promising educational innovations only through the lens of their discipline. Using a cognitive interview methodology, we asked how teachers with professional formation in different disciplines would approach a project that purported to connect those disciplines. On the one hand, we found that lesson planning and implementation is a broadly similar task for various types of teachers. On the other hand, we also found that, for the most part, both science and journalism educators focused more heavily on the aspects of a science journalism project that fit within their own discipline. Yet all teachers we interviewed were interested in the possibilities a cross-curricular project opens, which suggests the need for further research on implementation and uptake.

KEYWORDS

STEM education, journalism education, storytelling, cross-curricular, cognitive task analysis, expert strategies

1. Introduction

A number of recent studies have converged in identifying storytelling as a promising way to increase interest in science (e.g., Dahlstrom, 2014; Polman and Hope, 2014; Csikar and Stefaniak, 2018; Green et al., 2018; Finkler and Leon, 2019; Joubert et al., 2019; Kapsala and Mavrikaki, 2020; Neeley et al., 2020). It is, perhaps, unsurprising that bringing storytelling into the content area classroom makes the content feel more relevant (Landrum et al., 2019). What about bringing content into the storytelling classroom, though? And are teachers equipped to take on either of these approaches?

This paper starts from the case study of a cross-curricular STEM storytelling program. Most participating teachers received degrees and early professional formation in journalism, English education, or both. A few years ago, one of them described participating like this: "I wasn't just a journalism teacher; I was a science teacher and it was exciting." But how easy is that switch for teachers? That is, how do STEM teachers and journalism teachers approach teaching? After all, most current teachers are socialized into disciplinary norms and identities through their pre-service education, which instills a "professional vision" (Goodwin, 1994).

This exploratory study seeks to answer the following research question: How do teachers with different disciplinary backgrounds approach a project that purports to connect them?

1.1. Some challenges for cross-curricular education[1]

Over the last few decades, U.S. primary and secondary education have started to embrace cross-curricular innovation. Shifts in this direction go by many names, including problem-based learning (Savery, 2006), project-based learning (Bell, 2010), and STEM (science, technology, engineering, & math) education (Holmlund et al., 2018). Newer educational frameworks such as the Next Generation Science Standards (NGSS Lead States, 2013) and the Framework for 21st Century Learning [P21 (Partnership for 21st Century Learning), 2019] also move beyond traditional disciplinary boundaries, requiring both students and teachers to rethink their classroom roles (Klein, 2006).

Research has established that a lack of cross-curricular teacher education and professional development is a key barrier to implementing integrated interdisciplinary education. After all, most current teachers received their primary professional education in a single discipline. Both pre-service teacher education programs and in-service professional development opportunities that prepare teachers with content knowledge in multiple fields are relatively new (Honey et al., 2014).

For example, Shernoff et al. (2017) identified the following barriers to integrated STEM education through a series of key informant interviews with teachers and administrators:

- an overall lack of understanding about how to integrate the areas;
- lack of familiarity with content and standards outside teachers' core subject area;
- the need for more time for both collaborative planning and integrated instruction; and
- logistical hurdles such as scheduling and testing.

Administrators, in particular, observed that most current teachers started teaching before this cross-curricular turn, and that pre-service teacher education has not yet caught up with the trend towards increasing integration. Teachers in Shernoff et al.'s study also identified specific needs that would allow them to more effectively integrate the STEM disciplines: time for collaboration, more professional development, and resources like examples and lesson plans. Critically, this research demonstrated that both teachers and administrators saw cross-curricular collaboration as central to integrated STEM education.

Because the movement to integrate STEM education grows out of a recognition of existing connections between the STEM disciplines (Honey et al., 2014), these challenges may be even more pronounced for cross-curricular approaches that also incorporate the arts and humanities. For example, content-area teachers have little formal preparation in reading (Norris and Phillips, 2003) or writing pedagogy (Kohnen, 2013), and they rarely feel comfortable teaching writing (Kiuhara et al., 2009; Kohnen, 2013).

1.2. Storytelling and learning

Storytelling is the oldest and most ubiquitous means of teaching and transmitting knowledge. Stories have been used to entertain and also to teach the behavioral norms and fundamental concepts of a society, and storytelling persists as a popular teaching tool. There are both cognitive and affective-motivational reasons for the ubiquity and power of storytelling. The cognitive and affective foundations for improved *learning from "hearing" stories* have been well-documented in the research literature, both from the perspective of general pedagogy (for review see Landrum et al., 2019) and science pedagogy specifically (for reviews see Dahlstrom, 2014; Neeley et al., 2020). However, the benefits of *learning from telling stories* have seldom been studied. For example, in a recent systematic review of research on digital storytelling in secondary education, only a small fraction addressed any kind of learning: 57 out of 1,063 studies published January 1993 to December 2018 (Wu and Chen, 2020). Nevertheless, one consistent finding is that the opportunity to tell stories helps students feel more motivated and emotionally engaged in learning. This aligns well with previous research on Student Reporting Labs (see Section 2.1) applied to STEM learning (Fraser et al., 2019) and to health sciences learning (Voiklis et al., 2022): telling STEM stories helps students see the relevance of STEM and feel more engaged in the STEM learning process. Moreover, evidence has been accumulating from these and other research projects by the same team that relevance judgments are the motivation for using the information reported in the news in one's current reasoning and for establishing intentions for information sharing and future learning (preliminary results in Voiklis et al., 2022).

Examining storytelling in the science classroom, Morais (2015) and Morais et al. (2019) found that older students telling stories to teach chemistry concepts to younger students was an effective strategy, one that motivated both groups of students to learn and captivated their interest. Yet while both studies suggest that storytelling holds much promise as a pedagogical strategy for increasing student motivation, perceived relevance, and interest in STEM topics, the authors indicate that more research is still needed to capture the mechanisms through which STEM storytelling works to improve students' cognitive skills. It is also worth noting that these studies focused on students' learning and not on the process of teaching STEM through storytelling. It is the latter focus that the present article takes up by examining the cognitive representations that educators leverage when considering how to implement a cross-curricular STEM storytelling project in their classrooms.

1 We use *cross-curricular* as an umbrella term for *multidisciplinary*, *interdisciplinary*, *transdisciplinary*, etc.

1.3. Cognitive representations

Easing the transition into cross-curricular education will require applying instructional design principles to teacher-facing materials for cross-curricular projects (in addition to the materials used by students). To that end, it would help to first assess how teachers across the curriculum conceptualize cross-curricular projects (Means, 1993). When based upon a deeper understanding of the ways in which instructors think about cross-curricular teaching, the instructional design of cross-curricular programs and professional development materials could meet teachers where they are.

For example, in the present case (a STEM storytelling program), a journalism teacher would likely have a very different conceptual representation of STEM storytelling than a physics teacher. This is largely due to differences in discipline-specific education. For example, the journalism teacher's education may have predominantly focused on communications, media, and/or ELA. In contrast, the physics teacher's background may have focused almost entirely on physics, though perhaps supplemented by a course or professional development workshop on science communication. Those representations likely determine their approach to teaching STEM storytelling, and likely how they understand both STEM and storytelling.

Cognitive task analysis is a widely used approach to assess the conceptual representations that experts and novices bring to a task (for examples of uses in education see Clark et al., 2007; for meta-analyses of effectiveness of professional development materials based on task analysis see, Tofel-Grehl and Feldon, 2013). In general, task analysis is used to make explicit the implicit knowledge experts bring to bear in performing a task and addressing common task demands (see, e.g., Hutchins, 1996). In this way, expert knowledge can be made available to novices, who, by definition, lack experience with the task and might see common task demands as novel and, perhaps, insurmountable. In many ways, all existing teachers are novices to cross-curricular educational approaches (*cf.*, Shernoff et al., 2017).

For the present cognitive task analysis, we relied on a cognitive representations approach (Black et al., 1995). Black et al. (1995) suggest knowledge can be organized into four types of representation: factual knowledge (knowing that something is true), imagistic knowledge (knowing what something looks like), procedural knowledge (knowing how to do something), and system knowledge (knowing why something works).

While project-based learning (PBL) is now widespread in many schools (Kokotsaki et al., 2016), it rarely requires teachers to stray too far from their disciplinary background and the types of assignments available to almost any teacher (papers, posters, and presentations). In contrast, a STEM storytelling program would require facility with (1) topics in STEM and STEM communications (including (2) the basics of narrative and storytelling), as well as (3) comfort with the (audio, video, etc.) tools of modern journalism. These three types of skills have historically been found in distinct educational departments. That said, journalism teachers[2] have some experience bringing together disparate topics into a single project. In fact, many journalism teachers may not recognize STEM journalism as a discrete specialty within journalism that requires specialized skills, given that many non-specialized professional journalists also struggle with this recognition (Menezes, 2018).

2. Materials and methods

We conducted a series of cognitive interviews, or "thinkalouds," with sixteen educators in which we asked them to review a classroom activity. Thinkalouds can reveal "a range of different ways of using the resource, many of which had not been anticipated by the researchers" and help researchers "identify navigational and other issues which would not have been evident from questionnaire or focus group data" (Cotton and Gresty, 2006).

These sixteen educators represented three different groups. Six of them were journalism teachers who were experienced users of the curriculum. Five of them were journalism teachers who were new users of the curriculum, and the last five were science educators. Details about the educators are available in Table 1.

2.1. The context: StoryMaker, a cross-curricular STEM storytelling project

The StoryMaker platform[3] brings youth journalism projects from PBS NewsHour's Student Reporting Labs (SRL) to a broader audience of educators. Resources and lesson plans are all available through the platform, and teachers can make use of them whether or not they have access to the support of program staff. This platform includes STEM journalism curriculum alongside assignments on a wide range of other beats. Topic prompts are designed to encourage open-ended inquiry into a wide range of STEM disciplines; these prompts include questions about climate change, national parks, engineering and infrastructure, brain science and mental health, invention and innovation. The STEM story prompts and curriculum were developed to align with the Next Generation Science Standards and Common Core Standards.

2.2. About the protocol

We used a knowledge representations approach to cognitive task analysis (Black et al., 1995), which can "describe job performance not only in terms of overt behaviors, but also in terms of the underlying knowledge content and thinking processes [and] capture not only the formal but also the informal aspects of the job" (p. 24).

In order to elicit knowledge representations about the task of teaching a STEM storytelling project, we asked a group of teachers to talk us through their thought process as they reviewed a potential project available on the StoryMaker platform. The goal of the project was for students to make a short videojournalism report about effects of climate change in their local area, combining scientific knowledge with storytelling skills.

2 And, to be sure, others who teach electives at the secondary level.

3 story-maker.org

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TABLE 1 Pseudonyms and teaching context for participants.

Pseudonym	Category	Subject(s) taught	Grade levels
Blake	SRL Experienced	Co-teaches SRL as a journalism elective in 3 schools	6–12
Carter	SRL Experienced	Digital video production, Intro to TV production	9–12
Max	SRL Experienced	Intro to video production, broadcast journalism, film/documentary production	10–12
Tayor	SRL Experienced	Media electives	9–12
Tory	SRL Experienced	Videojournalism	6–8
Jamie	SRL Novice	Teacher professional development	K-12
Jesse	SRL Novice	Intro to journalism, broadcast journalism	9–12
Layne	SRL Novice	Movie production / TV broadcasting	6–9
Luca	SRL Novice	Independent study	Primarily K-3
Zev	SRL Novice	Video production	9–12
Corey	Science	Biology, earth science, marine science	9–12
Emerson	Science	STEM	6
Kai	Science	All (classroom teacher)	1
Teddy	Science	Physics	10–12
Micah	Science	Science	7

We asked teachers to navigate through the page, reading aloud and explaining their decisions to skip sections or click through links, asking questions, and articulating how they could use this assignment. Our protocol included a considerable number of follow-up questions and prompts, although which ones we used depended to some extent on the path each teacher followed.

The protocol differed slightly for the three types of teachers we interviewed, particularly the preamble. Teachers who were already familiar with StoryMaker, including both the experienced teachers and the "novice" journalism teachers, did not need as much explanation about the context of the site. We also asked slightly different questions about the types of resources they were already using on the basis of these differences. See the Supplementary materials for both versions of the thinkaloud protocol.[4]

2.3. Subject recruitment

We recruited three different types of teachers for the purpose of comparison: experienced SRL and StoryMaker teachers, new teachers who had expressed interest in SRL and StoryMaker, and science teachers. Both veteran and new SRL teachers were recruited through a feedback survey on the StoryMaker website between January and February 2022, which was linked in the ribbon on the homepage for logged-in users. Of 30 teachers who provided feedback, 18 said they were willing to be contacted, and we spoke to eight of them: five veterans and three who were relatively new. In May 2022, we conducted additional recruitment through the StoryMaker newsletter, netting us one more veteran teacher and two more new teachers. Nine of these eleven teachers primarily teach journalism or video production, with the tenth in a support role providing PD for fellow teachers and the eleventh teaching much younger students.

We recruited five science teachers through a range of strategies in August through October 2022. Two were respondents to a prior survey about barriers to implementing a videojournalism program on Prolific, an online panel platform; two were recruited through researchers' personal networks; and one was recruited by StoryMaker staff. None of the five science teachers had used StoryMaker previously.

2.4. Analysis

After all interviews were transcribed, two researchers coded each transcript for the presence of the four cognitive representations—factual knowledge, imagistic knowledge, procedural knowledge, and system knowledge—throughout. Given the relatively small number of interviewees, we did not attempt to reach interrater reliability but rather discussed our impression of the interviews until we reached consensus, typically additively. That is, items most often received additional codes after discussion, since the cognitive representations are not mutually exclusive.

3. Results

Our examination of the thinkaloud transcripts revealed that journalism and science teachers approached cross-curricular education similarly in many ways. They often framed their responses to our questions in terms of the specific demands that StoryMaker's STEM storytelling project would require them to meet, along with the strategies they would employ to successfully overcome those challenges. At the same time, all teachers tended to make sense of the task through their own disciplinary lens. To understand the processes through which teachers identified certain strategies and demands, we apply concepts from cognitive task analysis. In particular,

4 https://bit.ly/45czJmG

we leverage the concept of knowledge representations to show how teachers' expert knowledge conditioned the ways in which they framed the project and envisioned its development in their classrooms.

The sections below are largely chronological: teachers follow a similar process in assessing and implementing materials regardless of discipline. Ultimately, the significant overlap between the different groups of teachers who participated in our study indicates that STEM storytelling can be seen as relevant and valuable across multiple disciplines. However, the differences in teachers' approaches also suggests that what students get out of it may depend on those teachers' primary discipline. The teacher's primary discipline functions as system knowledge that they bring to STEM storytelling, because discipline largely determines which parts of the assignment they see as most important for students to learn. In this sense, STEM storytelling offers a useful case for studying what cross-curricular project development might look like in different classrooms and what skills it might require of teachers, to spark students' interest in new areas while encouraging measurable improvement in the course's core discipline.

3.1. Managing the curriculum

All of the teachers (whether in journalism or science) focused on one major demand of implementing a cross-curricular project such as the STEM storytelling project on StoryMaker: Integrating the project within their required curriculum. Teachers relied most heavily on system knowledge of how K-12 education operates in their schools, districts, and states to envision the strategies they would utilize to meet these demands. Because standards are linked to particular disciplines, we saw clear differences between science and journalism teachers in which standards they saw as critical.

3.1.1. Standards alignment

Both science and journalism teachers found aligning the project to school/district standards to be an important element of adopting a long-term cross-curricular project. When discussing standards alignment, all teachers relied on their system knowledge of their school and district's standard requirements. However, teachers paid more attention to the standards that fell within their own discipline.

For example, science teacher Emerson leveraged system knowledge to explain how the different pieces of the state and national education standards puzzle would ultimately align with the STEM storytelling prompt. Specifically, Emerson told us that the project would align with specific science standards, as well as several other "anchors and standards" that their state requires teachers to target, including problem-solving and ELA standards related to public speaking and presentation methods. All of these would likely need to be attached to an "interdisciplinary project" like this one, they said.

For SRL/StoryMaker newcomers Jamie, Luca, and Zev, standards would play a decisive role in whether they would be able to successfully implement a cross-curricular project in their classes. Jamie, whose job is to support other teachers with resources they can integrate, told researchers that the more standards a teacher can align such a project to, the better, since assessment is "very large in the teacher world." Given their role, Jamie listed connections to standards across the curriculum, particularly science and ELA, suggesting that teachers' focus would depend on context. Zev also noted the importance of aligning the prompt to standards and specifically mentioned that they are required to address the technical and "hands-on aspects" of storytelling.

While journalism teachers focused on storytelling alone, some science teachers suggested framing the project in terms of *both* its science and storytelling aspects. Corey explicitly noted the NGSS alignment and the focus on socioemotional impact because both of those were school-level priorities. Similarly, Kai's interpretation of the StoryMaker project went beyond the assignment's uses to teach either journalism or science in isolation. Instead, Kai explained, it really aligned with "some parts of this curriculum that [are] not just about science," such as those that teach students how to "interact with each other respectfully." Kai also noted that their administrators review lesson plans primarily for the standards cited, so they found it useful to have both literacy and science standards made explicit. Like Kai, Micah also expressed their understanding that storytelling should not be tied to any given discipline, but should instead be seen as a way to make education "relatable and meaningful" across contexts. In the context of science, they described storytelling as more than "a recollection of facts or sequence of events that occur," and said that its primary benefit is requiring students to "translate a story" into a specific format and use "higher level thinking skills" to communicate complex ideas and dense content to an audience.

3.2. Making a problem meaningful

One task demand that many teachers talked about involved making schoolwork (in this case, the problem of climate change) meaningful for their students. When discussing the strategies they would use to meet this demand, teachers across disciplines made use of diverse knowledge representations, including factual and procedural knowledge as well as imagistic and system knowledge. While teachers of both journalism and science found it important to make the STEM storytelling project meaningful for their students, only journalism teachers saw professionalization or, making their students feel like journalism professionals, as a valuable strategy.

3.2.1. Familiarizing students with an abstract problem

Both science and journalism teachers would elicit connections between climate change and students' daily lives and schools as a way of making STEM storytelling meaningful. For example, Micah, a science teacher, indicated a need to familiarize climate change by bringing it close to home, which is "less abstract than something like polar bears and their habitat." That is, they would ask students to identify "things that happen to us on a day to day basis … that could be potentially related to this particular issue." This suggestion was based on Micah's factual knowledge about what would help students stay engaged throughout the process. Carter, a journalism teacher and SRL/StoryMaker veteran, agreed with Micah that they would "sell" the project to their journalism students by making connections to their school. Specifically, they suggested that they might point students toward the different clubs in their school, especially the environmental club, to interview local "experts" and learn more about climate change.

Luca, a journalism teacher new to SRL and StoryMaker, suggested that one of the ways they would familiarize climate change for their students would be through making adjustments to the key questions listed on the StoryMaker website. Instead of pulling the questions directly from the site, Luca would adjust the wording to ask students how weather, wildfires, and other climate change phenomena hurt or impact them personally, rather than asking about the general impact on the community. Other journalism teachers also said they would try to connect climate change to students' day-to-day lives and communities. Layne, Tory, and Jamie all suggested tapping into specific features of their cities' environments, like rivers or power plants, to bring the topic home for students.

3.2.2. Making students feel like "professionals" (an authentic learning experience)

Journalism teachers also took extra steps to make their students feel like professionals in the media industry, which was entirely independent of the topic. Meanwhile, science teachers did not indicate that they would try to make STEM storytelling meaningful in this way. In fact, some science teachers explicitly rejected this approach because they do not teach the prerequisite skills.

As SRL/StoryMaker veteran Max explained, students enjoy these projects because they do not "feel like a class to them." Instead, when students are engaging in hands-on activities like filming and editing, they are more likely to "feel like broadcast journalists" or "professionals." Tory, an SRL/StoryMaker veteran like Max, also said that students benefit from feeling like professionals. One way teachers can help them achieve this is by teaching them the relevant journalism jargon and terminology, particularly up front.

3.3. Mental preparation

Mental preparation for a storytelling project was a task demand that many teachers discussed in their interviews. To meet this demand, teachers tended to rely on two different strategies: to prepare themselves mentally, collaboration; and to prepare their students mentally, development or "warm up" procedures. The first, collaboration, entailed teachers working either with their students or with other teachers to lay down the groundwork and prepare for a cross-curricular STEM storytelling project.

With one exception, only teachers who were new to the SRL/StoryMaker platform (including science teachers) spoke about needing to prepare themselves. SRL/StoryMaker veterans, on the other hand, did not tend to see collaboration as necessary, both because they already felt mentally prepared and because they did not focus on the STEM-specific aspects of the project. On the other hand, all types of teachers found student mental preparation through developmental procedures important.

3.3.1. Collaboration

The most exciting part of such a project, according to science teacher Emerson, would be the opportunity it presented for interdisciplinary work and collaboration among different kinds of teachers, but the success of that collaboration could depend heavily on school culture. Science teacher Corey seemed to agree with Emerson, noting that collaboration would be necessary due to their own gaps in knowledge about video production. To address this issue, Corey asked, "How am I supposed to critique [my students] when I do not even know how to do it?" Because of the limits of Corey's own factual and procedural knowledge related to the storytelling aspects of the assignment, they would instead create their own project "along with the kids," at least the first couple times they implemented the project.

Jamie, who supports other teachers with professional development and is new to SRL and StoryMaker, explained that they would leverage collaborative strategies on the basis of their factual knowledge about what teachers would find challenging about a STEM storytelling project. They saw this project fitting equally well in the science and ELA curricula, with the challenge being "not as much about the subject matter as about how comfortable teachers are in taking risks." That is, Jamie said that a "non-traditional project" like that on StoryMaker would likely intimidate some teachers, especially those who "did not learn to teach like that." Journalism teacher and SRL/StoryMaker newcomer Luca also admitted that in addition to their students' lack of knowledge in certain areas, they would also need to confront their "own ignorance about some things" in order to successfully teach StoryMaker's STEM storytelling project by researching and learning alongside their students.

3.3.2. Development or "warm up" procedures

Teachers who offered "warm up" activities to support students' mental preparation relied most on procedural knowledge, especially when discussing how they would incorporate such activities into their lesson plan. Additionally, regardless of their discipline, all teachers recognized the need to "warm up" their students for a STEM storytelling project, and they proposed a number of ways to meet this demand. In general, science teachers were more concerned about "warm up" procedures for journalism skills, and vice versa.

Science teacher Teddy noted that they would need to mentally prepare their science students for a STEM storytelling project by teaching them some basic communication skills. To that end, they said they would devote at least two to three modules over the course on how to communicate, with at least 15 min of those modules dedicated to learning how to speak on camera. For Micah, another science teacher, engaging in various "development activities," such as teaching their students the meaning and practice of collecting B-roll, would help students fully grasp the procedures underlying the assignment.

Carter, a journalism teacher and SRL/StoryMaker veteran, mentioned that they would likely make use of the classroom discussion guide on StoryMaker to prepare their students for the project and help them think critically about the topic. Max, a journalism teacher and SRL/StoryMaker veteran, would take additional steps to mentally prepare their students for the project. First, they would begin by helping them think through what climate change looks like in their community. They would also ask students key questions, such as "What is community?" to get them thinking more deeply about the assignment.

Only one teacher proposed this strategy for their own mental preparation: Jamie, who is new to StoryMaker and whose job is to support colleagues with professional development, said that they would need to read all the climate-related articles on StoryMaker's website in advance.

3.4. Working with students of differing ability

No classroom is perfectly homogeneous: students bring different knowledge, interests, and skills to the classroom. And teachers need to make a lesson work for all of them. Teachers identified two strategies: scaffolding system knowledge and scaffolding procedures. With few exceptions, only teachers who were unfamiliar with the StoryMaker platform (that is, science teachers and teachers who were new to SRL/StoryMaker) were concerned with managing their students' differing abilities. Meanwhile, SRL/StoryMaker veterans typically had factual knowledge about their students' familiarity with the procedures involved in this assignment, as well as strong procedural knowledge about the assignment itself.

3.4.1. Scaffolding system knowledge

Teachers leveraged both imagistic knowledge and procedural knowledge when offering expert strategies related to the scaffolding of system knowledge (i.e., seeing the big picture). One of the main approaches teachers took to scaffold students' system knowledge was through *group work*. Both science teacher Micah and SRL/StoryMaker newcomer Jamie suggested that group work had multiple benefits. Micah said they would likely create groups around diligence and motivation level, rather than allowing students to select their own groups. By ensuring that each group had different levels represented, group work would make it possible for students to support one another, which in turn would help teachers effectively manage their time, instead of "run[ning] around to every single one of your 35 students." Jamie offered a similar rationale: group work would likely encourage the students to share ideas and move through the project's process more effectively They also agreed that placing students into groups would likely benefit teachers, as they would then be able to focus their attention on a small number of groups rather than dividing up their time between a larger number of individual students.

3.4.2. Scaffolding procedures

Teachers overwhelmingly used procedural knowledge to talk about their approaches to scaffolding classroom procedures. For example, science teacher Corey leveraged procedural knowledge to advise that science teachers go for the "smart move" of not giving students the full project roadmap at the beginning of the project, but instead by *introducing the project step-by-step* and slowly introducing the "more detailed aspects" of the project later on. Science teacher Teddy agreed with Corey, saying that they would take up the project in small chunks to get their students to start planning and "figuring out what they want [to do]" before jumping into the technical aspects of video production. SRL/StoryMaker newcomers Jesse and Luca both described a similar strategy to help students avoid becoming overwhelmed.

All types of teachers explained that they would likely also make adjustments for the different learning styles of their students, particularly by *offering multimodal instruction*. SRL/StoryMaker veteran Max told researchers that they offer instruction in multiple ways, both hands-on and verbal, to differentiate for different kinds of learners. Zev, a journalism teacher new to SRL and StoryMaker, said that they try to utilize a lot of visual elements in their teaching, as many students are highly visual learners. To help students who struggle with reading succeed, Zev would make sure to adjust the project to be more "video-based [and] visual-based," since these types of materials tend to go over well. And Blake, an SRL/StoryMaker veteran, also explained that they would use visual examples to help students understand "where they are at and where they are going." In providing students with visual examples of the process of creating a STEM storytelling project, they would effectively create their own visual version of StoryMaker's text-based "roadmap," a tool to help students locate themselves within the various stages of pre-production, production, and post-production.

Some of these changes were connected to making the project accessible for students outside the target age range. Kai, a science teacher, noted that they would likely want to adjust StoryMaker's project for students with a more visual inclination. Kai utilized imagistic knowledge in their suggestion that teachers might benefit from transforming StoryMaker's worksheets into "cut-and-paste" activities for students. Since Kai teaches first-graders and the assignment is designed for middle- and high-schoolers, making adjustments like this one would be particularly important. Luca, who also teaches younger students, mentioned that they would adjust the project's scope. In particular, since younger students may be more interested in speaking about climate change in terms of what it means to them rather than in the abstract, Luca would let students elaborate on this personal aspect of climate change.

3.5. Project management

For a long-term project like this one, teachers identified project management as an important set of demands. The website identifies the project as taking 4–6 weeks, which requires awareness of how each component contributes to the whole. We did not see clear disciplinary or experience distinctions in project management strategies.

3.5.1. Time monitoring

Science teachers indicated they would make use of time monitoring strategies to keep their students on track throughout the project. Micah, for example, said that they would incorporate an "efficiency entry" into their grading rubric to help students stay on task. The efficiency entry would evaluate whether students are "approaching," "exceeding," or "going above and beyond" the outlined expectations, and whether they are advancing at the appropriate speed. Corey, another science teacher, leveraged factual knowledge about their students' strengths and weaknesses to assert that time management skills are one of the most important lessons they teach in their classroom, especially because such skills often take "a long time to learn."

Like the science teachers, Tory, a journalism teacher and SRL/StoryMaker veteran, described some of the time monitoring procedures they would have students do, including a "Daily Stand-Up," where students share, first with Tory and then with the other members of their film crew, what they have accomplished and what they still need to do to finish a given assignment.

Teachers also told us that time monitoring is not only important to keep students on track, but also to keep themselves up-to-date when implementing a long-term project in their classrooms. Layne, a journalism teacher new to SRL and StoryMaker, said that they typically make slides in order to keep themselves from becoming "scatterbrained" as they teach and to stay on track. Jesse, another journalism teacher new to SRL and StoryMaker, said something similar, explaining that they find themselves gravitating toward ready-to-go materials that help them keep pace during class planning sessions. Since they often have less than an hour to plan several classes, they told us that they typically end up using whatever materials they have that are “the easiest to implement.” Like this, they succeed in both monitoring their time and planning for all the courses they need to teach.

3.5.2. Changing the timeline

Several teachers new to StoryMaker – both in science and journalism – indicated that they would alter the project’s suggested timeline to meet project management demands. Science teacher Teddy, for example, considered how long such a project would take to implement in their class. But instead of utilizing factual knowledge about their students or procedural knowledge about the steps involved in planning such a project, Teddy leveraged imagistic knowledge when considering the project’s unique task demands by envisioning what their calendar would look like as they and their students advanced through the project. Finally, Teddy suggested that what they would be “looking at” would be around “30 to 50%” of their planning and teaching time “for the better part of…four weeks.” In other words, Teddy explained, a STEM storytelling project would be a “long term project distributed over a long amount of time.”

Similar to Teddy, SRL/StoryMaker newcomer Layne also thought that they would need to adjust the STEM storytelling project’s timeline, in order to make it manageable for students. Layne arrived at this idea when making inferences about how much time it would likely take their students to complete such a project. Ultimately, Layne thought, the project would have to span an entire quarter, rather than the four to six weeks suggested on the website. Such a tight timeline, Layne explained, “would be a little daunting” both to them and their students. Finally, another journalism teacher new to SRL and StoryMaker, Zev, made a similar suggestion using their knowledge of classroom procedures. They told us that they would likely have to adjust the proposed timelines, especially for the more complex lessons listed on the StoryMaker website. In fact, Zev would likely double the suggested timelines for their class, at least for “planning purposes.”

Program veterans, on the other hand, generally found the timeline on the site to be accurate, although they might make small changes to accommodate a vacation, a shorter semester, or a class that met particularly frequently or infrequently. In general, these teachers had already committed to these kinds of timelines and knew that their students already had or would gain prerequisite knowledge.

3.5.3. Procedure adaptation and flexibility

Whether they taught journalism or science, the teachers we spoke with told us that one expert strategy they would utilize to meet project management demands would involve adapting and building flexibility into the project’s procedures. Many teachers suggested that *incorporating additional structure* into the project’s procedures would be helpful for both them and their students to successfully complete the assignment. For Micah, a science teacher, simply saying to students, “Pick a climate change issue [and] go research it,” would be too unstructured for this kind of project. Instead, Micah would add structure to the project by giving students “exemplars” in the form of a “menu” that lists the important steps students should take and the expected outcomes of each step. For journalism teachers, some of this structure would involve giving particular tasks to specific students, who they would ask to work in teams. For Tory, an SRL/StoryMaker newcomer, one person on each student team would take on an “editor” role, while another would be the team’s “director,” and yet another the “journalist.” When split into different roles, students would be able to focus on perfecting the procedures involved in completing a STEM storytelling project.

Program veterans were either able to *skip components* they knew they had already taught, or *combine the project with external resources*. Taylor, an experienced journalism teacher familiar with SRL and StoryMaker, explained to researchers that they would likely adapt many of the materials found on StoryMaker by skipping “whole sections,” adding new sections, or merging “something I’ve done before” with a new lesson on the StoryMaker website. Another SRL/StoryMaker veteran, Carter, said something similar to Taylor. They leveraged their knowledge of the procedures involved in journalistic storytelling and imagined that they would likely want to “condense” much of the information on the StoryMaker website in order to make the lesson shorter and more manageable.

Finally, all types of teachers said that *introducing activities one at a time* would be necessary for meeting the project management demands of a cross-curricular STEM storytelling project. For example, Teddy, a science teacher, said they would divide the project into smaller discrete steps and might not give students full visibility into the long-term plan. Doing so would allow them to conduct ongoing assessments and to better support their students with accountability. Moreover, Teddy said that their students would likely succeed in this type of project, so long as they were given “exactly enough rope” to advance through the project’s multiple steps. Similar to Teddy, SRL/StoryMaker veteran Tory leveraged procedural knowledge to think through the different steps they would take to get students started with the project. Each of these steps, they explained, would have to be taken in isolation, which Tory understood as a way to make the different tasks involved in STEM storytelling bite-sized and manageable for their students. Layne, an SRL/StoryMaker newcomer, also explained that they would want to break down the different steps of the project into small pieces for their class. Introducing all the complex steps at once would be “a little overwhelming.”

3.6. Holding students accountable: assessment strategies

As Jamie, an SRL/StoryMaker newcomer and journalism teacher, noted, grades are inescapable for teachers. That said, teachers need a “clear cut way” to grade students, and they must always consider how they are going to grade “with equity.” Science and journalism teachers generally assessed different aspects of the project; in fact, most would say it was their job to do so.

As science teacher Teddy explained, their class sets students up to produce extremely informative scientific content about the changing environment, but they would likely struggle with the technical aspects of video production. That being the case, Teddy said they would focus their attention on grading the science within the STEM storytelling project, rather than the quality of the production. Ultimately, when it comes to grading such a project produced by a group of advanced science students, Teddy told us there is one simple rule: “I think if you were going to do this for science,” they said, “you need to drop your quality expectations like a stone.”

Journalism teachers, on the other hand, assessed technical skills like camera work and editing, as well as production quality.

4. Discussion

This article expands on the current literature related to STEM storytelling by examining the cognitive representations that educators leverage when considering how to implement a cross-curricular STEM storytelling project in their classrooms. Our results show the promise of STEM storytelling across the curriculum and point to some of the challenges that educators must overcome to successfully develop cross-curricular lessons and integrate other modes of teaching into their own discipline-specific pedagogy. The program's primary audience to date has been journalism teachers, and we also heard clear enthusiasm from science teachers about bringing this kind of assignment into their classroom. In particular, science teachers said that storytelling might be more engaging for students who did not intuitively see the relevance of science.

At the same time, our results support Shernoff et al. (2017) argument that cross-curricular education presents a number of challenges for educators, many of whom receive professional development in one discipline and may not know how to integrate material and methods from other fields. We also show that the integration of multiple disciplines presents a major challenge of cross-curricular projects, especially with regard to student assessment: That is, the teachers we spoke with focused primarily on outcomes within their subject area. Even when teachers focused on standards across multiple disciplines, they tended to limit assessment, both formative and summative, to their own area. This suggests in turn that students are being exposed to multiple disciplines at once but may only be held accountable to the standards of a single discipline.

If the goal of STEM storytelling is for one educator to teach both science and journalism at once, curricula may need to include additional scaffolding. For example, SciJourn (Polman and Hope, 2014) specifically teaches students practices of science journalism, a specialized form of journalism that includes "knowing how to search for science information, evaluate the credibility of the information they find, and put that information in its scientific context" (p. 316). Applying general journalistic skills to science topics may fall short in some of these areas, because science journalism is epistemologically closer to science than is content-agnostic journalism. If we were to oversimplify: science and science journalism rely on the preponderance of evidence in evaluating claims; general journalism often tries to include multiple perspectives, and, ideally, provides audiences with enough information to evaluate claims by themselves (In practice, scientists and science journalists exhibit motivated reasoning often enough, and general journalists make evaluative judgments about claims and claimants in the course of their reporting). On a more serious note, truly cross-curricular teaching will require either extensive professional development opportunities or epistemic collaboration.

But there is also reason to continue building programs like the one we describe, which can be taught as both "Science through Storytelling" and "Storytelling about Science." Recently, the National Academies of Sciences, Engineering, and Medicine (NASEM) (2021) called for a radical rethinking of STEM education, arguing that STEM thinking is necessary for everyone, not just future scientists. To that end, recent policy recommendations call for cultivating student interest as the key route to educational equity (Renninger and Hidi, 2020). This program, which is primarily taught as a journalism class, offers students the opportunity to engage with science topics on their own terms. And that is an opportunity of value that teachers can offer *without* considerable investment in professional development.

Data availability statement

The datasets presented in this article are not readily available because participants were promised maximum possible confidentiality, and sharing transcripts would violate this promise. The interview transcripts analysed for this study cannot be fully de-identified, as the specific contexts and past experiences of teachers are referenced throughout. Requests to access the datasets should be directed to JV, johnv@knology.org.

Ethics statement

The studies involving humans were approved by TERC Institutional Review Board (IRB00005572, IRB Type: HHS). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

JB-L: Conceptualization, Methodology, Writing – original draft. MS: Conceptualization, Formal analysis, Investigation, Writing – original draft. JV: Conceptualization, Investigation, Methodology, Supervision, Writing – original draft. LC: Funding acquisition, Resources, Writing – review & editing.

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Conflict of interest

LC is Executive Director of PBS NewsHour Student Reporting Labs and contributed to the development of StoryMaker.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2023.1279861/full#supplementary-material

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