Children's Books for Research-based Outreach and Science Communication Pedagogy

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Abstract. Academics are encouraged to integrate scientific research with the public, but methods of doing so are often transient and insubstantial. Students and future scientists also require training and exposure to the importance of public outreach and science communication within STEM fields. Here, I describe two projects that provide a template for using children's books as an efficient and impactful means of science communication. The first part describes an international research project that

5 culminates in the writing, illustration, and distribution of a children's book. *Farzana's Journey* is a children's book based on multidisciplinary research on the pairing of the physical and human systems in coastal Bangladesh. Written, illustrated, and freely distributed in the Bengali-language, the book is a place-based tool to teach rural Bangladesh communities about the natural world and our scientific findings. Through the development and distribution of the book, we encouraged collaboration and public outreach with scientists, artists, and students concerned with enhancing educational and social opportunities in

10 rural communities. We also ensure a physical tie to the community after the project's culmination. The book sparks children's curiosity in the local environment, while also demonstrating a means for sustainable educational outreach with impoverished, remote communities. The second part of the paper provides an overview of how this type of science communication can be taught to early career scientists. Students in an intensive learning undergraduate course produce children's books about a scientific concept or process. I describe the curricular context and layout of the course, the assessment of deliverables, and the

15 impacts of the science storytelling process as a model for teaching communication literacy. Together, these efforts demonstrate the potential impact of children's books on science communication efforts among students, early career scientists, and local communities.

1 Introduction

Academics are encouraged to integrate their research with education and societal outreach. Many U.S. federal funding agencies,

20 such as the National Science Foundation (NSF) insist that scientists describe how their proposed research will have "broader impacts." Researchers must contribute not only to the growing fund of knowledge but to the more immediate societal good. The *broader impacts* criterion pushes researchers to engage in activities beyond their research, such as sharing data, mentoring graduate students, engaging undergraduates in research, translating research results into instructional materials for classroom use, increasing the participation of groups that because of gender, ethnicity, disability, and/or geographic location are under-

25 represented in science, enhancing the research and educational infrastructures at their institutions, or working directly with the

public (see for example Mathieu et al. (2009); Dyer (1999); Magrath (1999); Roberts (2009); Andrews et al. (2005)). Yet, too often societal engagement outside academia and with the general public is overlooked, unsuccessful, or transient at best.

One analysis of broader impacts statements from award abstracts reveals that 89% of researchers propose broader impacts for science, 43% discussed potential benefits for society, and 37% proposed dissemination activities beyond the scholarly commu-
30   nity (Roberts, 2009). Those who discussed potential societal benefits, however, were no more likely to propose dissemination activities than researchers who only discussed broader impacts for science (Roberts, 2009). Perhaps the science community has not yet achieved sustainable and efficient methods of science communication and outreach with the non-science community. Alternatively, perhaps barriers to participating in outreach (e.g. lack of time, lack of information about opportunities, and lack of support (Andrews et al., 2005)) inhibit scientists from engaging. Considering the challenges of international and intercultural
35   science communication (e.g., travel requirements, language, and cultural barriers, funding, etc.), it is obvious why large-scale societal outreach is a challenge.

Nevertheless, if researchers strive to achieve broader impacts, science communication and collaboration will be key. Effective articulation of science is critical to extending the reach of earth and environmental sciences education into settings and cultures to which access has previously been limited. Cultural and language hurdles can be overcome through mutually beneficial
40   collaboration with partners (Ray, 1999). Partners can include both research-related parties (e.g., research institutions, funding organizations, governmental agencies, etc.) as well as community communication facilitators (e.g., community leaders, media, artists, primary school headmasters, etc.).

This paper consists of two parts that assess the use of children's books in science communication. The first part describes an international research project that culminates in the writing, illustration, and distribution of a children's book. The second
45   part provides an overview of how this type of science communication can be taught to early career scientists. Together, these efforts provide a template for using children's books as a tangible and impactful means of science communication.

2   A children's book for international educational outreach

We used a children's book to (1) achieve a direct and sustainable STEM educational outreach with impoverished, remote communities in Bangladesh, and (2) build relationships with partners through collaboration during the creation and distribution
50   of the book. The collaboration included relationships with in-country partners like Dhaka University, Bangladeshi translators and editors, and primary and secondary schools, as well as U.S.-based groups like artists, media, and transdisciplinary academic institutions. The aim was to increase local students' understanding of the natural world and environmental change through a two-pronged sustainability effort. The first, and principal, vehicle for delivering this goal was through the presentation and discussion of the book itself, however the book was a tangible resource and community tie that persisted after the culmination
55   of the research project.

2.1 Project background

Bangladesh and its deltaic landscape is shaped by a broad range of environmental, economic, and social circumstances that mirror settings across many nations in Southeast Asia. Approximately 160 million Bangladeshis live in a country the size of Iowa, with one-third of the population living below the poverty line (Yoshino et al., 2017). In the coastal environment,
Bangladesh is increasingly affected by the longer-term pressures of sea level rise (Ali, 1996; Karim and Mimura, 2008), land subsidence (Auerbach et al., 2015; Wilson et al., 2017), and access to safe groundwater (Peters and Hornberger, 2020; Shumaker, 2017; Benneyworth et al., 2016; Benneyworth, 2016; Worland et al., 2015; Rahman et al., 2011) and their confluence with an increasingly dense coastal population. As a result, Bangladesh is considered one of the most vulnerable countries with respect to climate change (Huq, 2001). The increased frequency of cyclones, poldering (i.e. reclaiming and embanking islands),
and subsequent flooding add additional stress to this poverty-prone landscape, leading to livelihood changes and population displacement. The nation's environmental instability due to intense urbanization as well as multiple catastrophes–cyclones, floods, salinity, arsenic–has made Bangladesh a country of continuous research and policy innovation.

Approximately 30% of Bangladesh's population remains below the poverty line earning less than $1.9 USD a day (Kamruzzaman, 2021) and there are rural-urban and socio-economic disparities for entry and participation in primary school.
Bangladesh's primary education providers comprise a wide range of public and private schools, including those that are government-funded, privately funded and operated, and religiously funded (Sommers, 2013). Educational standards and infrastructure in rural regions of the country are limited at best. Most school children are not reaching their grade-level competencies and up to 80% of children between 6 and 16 are estimated to be out of school in rural areas (Rahman and Sharma, 2021). Students have little to no access to broadband internet and printed texts are often stored in facilities only accessible by teachers
and headmasters. The education model prioritizes rote memorization and is often not learner-centered. Some schools receive teacher training and government materials but this varies between communities. Primary school curricula encompass Bengali and English language, basic arithmetic, and history. The majority of rural students attend school until age nine.

Most residents of coastal Bangladesh have limited opportunities to travel outside of the region. Although some rural residents migrate in a seasonal fashion due to the lack of year-round employment or following a natural disaster (e.g. flooding or crop
failure); others do not migrate at all as the process is complex and resource-consuming (Poncelet, 2009). Migrant individuals and households rarely travel long distances, typically moving to the nearest urban area. Understanding of the geographic, sociopolitical, and environmental context of the region in relation to the country and globe is narrow.

The Vanderbilt Integrated Social, Environmental and Engineering (ISEE) Bangladesh Project took a multidisciplinary approach to investigate the coupling and coevolution of the physical and human systems in southwest Bangladesh. The relationship between environmental conditions, community livelihood, and human migration is multidimensional, and few studies have addressed exactly how this complex relationship operates and under what conditions the environment affects societal decision making. The complexity of these human-environment interactions in low-lying regions closer to the coast are especially significant with increased risk of climate change impacts. The overarching goals of the ISEE project were to (1) identify social and environmental factors most important in maintaining stability or for motivating decisions to migrate; (2) determine how these

90 factors differ within and across diverse social and physical landscapes; and (3) assess how these variables are likely to interact under a variety of scenarios for social and environmental change. The ISEE Bangladesh project was funded in part by the Office of Naval Research - Multidisciplinary University Research Initiative Award #N00014-11-1-0683, which granted five years of funding between 2011 to 2016. The research team published numerous studies exploring water quality and resources (Benneyworth et al., 2016; Ayers et al., 2016; Worland et al., 2015; Gunda et al., 2015), landscape alteration (Auerbach et al.,

95 2015; Wilson and Goodbred Jr, 2015), climate change (Ackerly et al., 2015; Peters et al., 2017), and associated social migration (Ackerly et al., 2015; Donato et al., 2016). Research had not been disseminated broadly, however, the research findings and increased understanding of the coupled human-natural system with the local residents cision makers until Fall 2017 with this children's book project. Prior to that time, few ties existed between the local communities and the ISEE research outcomes.

2.2   Methods: The creation of *Farzana's Journey*

100 This project involves the writing, illustration, and distribution of a place-based children's book title *Farzana's Journey: A Bangladesh story of the water, land, and people*. The main storyline follows a young girl, Farzana, who must walk a long distance to fetch her family's water. Her usual journey quickly develops into an adventure as she meets a variety of animal characters, who relay a story about her ever-changing environment and the subsequent human adaptation. More advanced topics including geomorphology, water availability, climate, and traditional livelihoods are further explained through complementary

105 diagrams throughout the narrative. Ultimately Farzana appreciates the uniqueness of her local environment and the adaptations of her ancestors and future generations. She feels a sense of agency in understanding and interacting with the world around her.

Prepared in English and translated to Bengali, the book targets young children in our research area but hopefully impacts teachers, parents, and local community leaders throughout Bangladesh. Bangladeshi community facilitators and translators provided feedback on drafts of the storyline to correct for cultural mismatches and miscommunications. Once translated, the

110 book was self-published by IngramSparks along with a second English version, now sold on Amazon. Examples of similar environmental children's books that have been successful include *Alber's And the Tide Comes in. . . : Exploring a Georgia Salt Marsh* 2012 and *Monisha and the Stone Forest* (Hughes, 2012; Hughes et al., 2015).

Collaborations with partners were essential, not only to the creation of the book, but also to the overall broader impact of the book. The text was crafted with the help of the Vanderbilt Writing Studio, where writers have the opportunity to meet with

115 trained writing consultants. Non-science consultants assisted with the book narrative and language to better craft a cohesive storyline and describe scientific research without the use of scientific jargon. The Curb Center for Art, Enterprise & Public Policy at Vanderbilt University developed partnerships with creative leaders affiliated with Vanderbilt University. The center offered resources and mentorship in initiating and implementing the children's book project by applying creative and entrepreneurial methodologies to problems. The Center funded a major portion of the project, but also provided training and support through

120 (1) invited structured discussion on topics of cultural differences and assumptions, (2) information on institutional outreach opportunities and limitations, and (3) anecdotal evidence of other successful creative initiatives sparked by academic research. The Curb Center also connected the author to Nashville's public art community by referring illustrators who contributed to the book ~~and~~ through exposure with an exhibition of the project in the Curb Center gallery space.
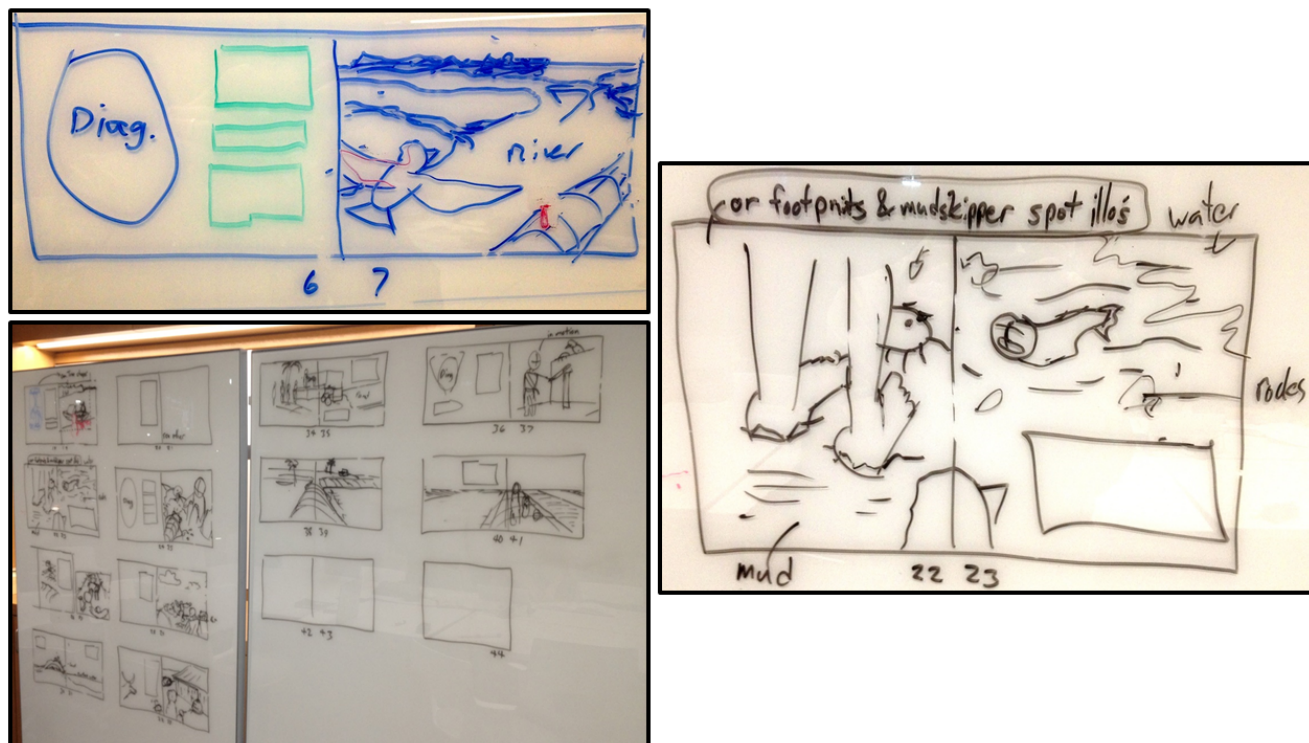
Figure 1. Storyboard of the narrative.

Perhaps the most meaningful collaboration, however, during the creation of *Farzana's Journey* was the illustration process.
125 Eight artists, who were previously unaffiliated with the research, worked alongside the author to co-produced the storybook
graphics (Fig. 1). Four of the artists were Vanderbilt University undergraduate art majors, one of which was a double major in
Earth and Environmental Sciences. Three artists were personal acquaintances of the author. The final artist was a Nashville,
TN local illustrator, who served as the creative director of the entire collaboration. The artists split illustration tasks, including
background painting, figure and animal sketching, digital coloring, and scientific diagram creation. With the help of the creative
130 director and graphic designer, these elements were combined and paired with the text to create the book.

These varied partnerships were essential in crafting the narrative and educational content of the children's book. Throughout
the book's development, authors, artists, and translators scaled a variety of science communication hurdles including (1) writing
for multiple audiences (Bangladeshi children, American children, and non-science community), (2) twisting a seemingly bleak
story of climate impacts into a story of human adaptability, (3) transitioning between scientific topics while maintaining the
135 storyline, (4) verbally and visually depicting the setting for unfamiliar audiences, (5) fostering cultural and environmental
relatability with Bangladeshi readers, and (6) preserving the intent of the story through translation from English to Bengali.
Although the success of the book can not be quantified without comprehensive surveying and structured interviews, anecdotal

evidence suggests that the narrative and illustrations sufficiently communicated the setting, scientific concepts, and the moral of *Farzana's Journey*.

140 ## 2.3 Impact

The book was distributed to educational institutions and individual children in southwestern Bangladesh during an October 2017 field visit (Fig. 2). The primary author and translator delivered 500 copies, written in Bangla, to 12 primary and secondary schools. Copies were left with each school library as well as handed directly to students. Translators facilitated a short presentation and gifting of the book to the headmaster, teacher, and classroom of each school. In the presentation, the story 145 was introduced to generate interest, discussion, and, potentially, local stories that related to the book narrative. The author and translators discussed the broader motivation and findings of the ISEE project with school administrators and teachers. They shared the intent of the book–to increase local students' understanding of the natural world and environmental change–to ensure that book was received as a gesture of gratitude for the local communities support in the ISEE research.

In the classroom, the translators discussed the formation of the delta, fluvial geomorphology, tides, water quality, and other 150 main concepts of the book with the students. Children of all ages were encouraged to think deeply about the local environment. Students conversed about *why* the environment is the way that it is and *how* environmental processes shape natural (and anthropogenic) change. Portions of the book were read aloud in each class and students were encouraged to continue their studies outside of the classroom. Although the conversations were brief, several teachers expressed their intention to resume the discussion with students at a later time. Many teachers even requested supplemental books and resources.

155 Project participants expressed increased "environmental empathy," which includes developing an appreciation and understanding of the environmental process, and increased cross-cultural awareness. Artists and writing consultants demonstrated high levels of synthesis and evaluation of the environmental concepts and technical scientific material (Bloom et al., 1956).

In Nashville, TN, the book was exhibited at the Curb Center gallery space and at multiple local bookstores. The book is also available for purchase on Amazon (S1) and has sold 120 copies as of July 2023. The book has been highlighted through 160 various media channels at Vanderbilt University and at academic conference presentations.

The children's book has been used in American high schools and colleges as an example of scientific communication. High school students were challenged to illustrate "wicked" environmental problems (e.g. sea level rise due to climate change, rainwater harvesting for drinking water, increased storm frequency due to global warming) for hypothetical peer students unfamiliar with the processes. The formation of the book also inspired the creation of an undergraduate course in science 165 storytelling.

3 A course teaching science storytelling

Here, I describe an intensive learning undergraduate course that enabled students to produce children's books about a scientific concept or process. A Roanoke College class of 15 STEM and non-STEM majors (1) learned the importance of public outreach and science communication within STEM fields, (2) expressed a greater appreciative understanding of the scientific content

Figure 2. Photographs taken during the distribution of the book.

170   presented in their own children's book, and (3) developed communication literacy to draft, publish, and exhibit a children's

book that explores a key concept in science. In the subsequent sections, I discuss the curricular context and layout of the course,

the assessment of deliverables, and the impacts of the science storytelling process. I hope similar intensive learning models

could be constructed to benefit science communication efforts among students, early career scientists, and local communities.

Table 1. Learning outcomes and associated assessment metrics of the Intensive Learning course.

Learning Outcomes	Assessment Metrics
Learn about and practice best practices for how to engage and interact with a range of audiences so your scholarship can inspire and educate.	Book analyses of children's literature
Acquire skills and gain confidence in communicating science to public audiences.	Group work and progress on children's book through drafts and storyboards
Communicate a scientific subject matter to non-science community through the creation of a children's book.	Final self-published children's book
Recognize and evaluate advanced aspects of communication that respond to the purposes and needs of an intended audience.	"Planning Children's Book" worksheet and discussion on multi-cultural children's literature
Make effective use of multiple drafts, revision, computer technology, peer and instructor comments, and collaboration to show understanding of communication standards.	Submission of multiple drafts that incorporate self, peer, and instructor feedback
Observe the accepted conventions of spelling, grammar, organizational structure, punctuation, delivery and documentation expected in public communication.	Submission of multiple drafts that incorporate self, peer, and instructor feedback
Interact effectively with audience members, engage opposing viewpoints constructively, and demonstrate active listening skills.	Observed collaboration with classmates
Reflect on learning the course's main concept in an intensive learning environment.	Mid-term and final reflection essays

3.1 Course context

175 At Roanoke College, the Intensive Learning (IL) Term provides students with the opportunity to learn in an immersive environment while fostering intense and purposeful faculty-student interchange. Students engage in a thoughtful, creative exploration of a focused topic during a time when students are enrolled in one and only one course. The majority of these courses are offered in May, during a three-week term. Although faculty develop the structure and intended learning outcomes specific to each course (Table 1), each course is require to include a IL-specific learning outcome: "Students will be able to critically

180 reflect on their learning about the course topic in an intensive learning environment."

3.2 Methods: Science Storytelling Course Experience

Storytelling is a vetted teaching practice, and it incorporates multiple student-centered learning strategies, such as reflection of deep learning, student engagement, and project-based learning. Storytelling can be used as science communication by helping close the gap between science and non-science learners and engaging audiences through multi-modal communication methods

185 (i.e., visual, oral, and digital) rather than simply the written practices that are more traditionally practiced in science fields. In addition to presenting information about scientific concepts or processes, storytelling can ground the information through a narrative (i.e., a story with a beginning and an end), evoking empathy that allows for deeper appreciation and understanding.

Figure 3. Photograph of children's books created by students.

At the start of the course, students were told that the course would not follow their typical academic experience. While students were still required to do research, present arguments, and think carefully about how an audience ~~will~~ respond, their synthesis of content would not culminate in a standard academic paper for the professor. Instead, the students would gain first-hand experience communicating inside and outside the classroom with the creation of their very own children's book. The course was composed of five distinct components: (1) daily attendance and participation in course discussion, (2) the completion and submission of an idea, (3) the drafting, creating, printing, submitting, and exhibiting of a self-published book, (4) collaboration with peers and stakeholders, and (5) reflection on the IL experience.

3.2.1 Structure and logistical considerations

The class met for a total of three and a half hours per day for three weeks. In a morning session each day, students completed creative warm-up activities (e.g., write a haiku, 15-minute free write, draw a self-portrait) and then were introduced to project-related concepts. Lecture and activity topics included science communication best practices, story arcs and character development, storyboard creation, illustration of landscapes, scientific diagramming, children's reading levels, illustration mediums, conversational writing techniques, and logistics of self-publishing. In a longer afternoon session, students were exposed to the children's section of multiple public libraries and given time to workshop their own scientific picture books. The class agreed upon the following project timeline for the 14-day course:

- Day 4: Scientific topic, narrative, and illustration ideas due
- Day 5: Email to primary school teacher due
- Day 6: First draft of book due
- Day 7: Revised draft with peer and instructor feedback due
- Day 8: Storyboard due
- Day 9: Front and back matter due
- Day 10: Midterm assessment due
- Day 12: Pre-print of book due
- Day 13: Self-published book due
- Day 14: Final assessment due; Book launch

During the first week of class, students were introduced to public librarians, primary school teachers, and a children's literature scholar. These individuals served as external resources as the student cohort developed their books. As the class progressed, students were allotted more individual time (and partner time if they were co-writing books together) to write, illustrate, and revise their books. Students were encouraged to start each day with a check-in followed by a discussion of the day's agenda. In most cases, students emailed individual updates to the professor and small working group members to report all tasks completed at the end of each day.

Students used Microsoft and Adobe products to write, illustrate, and lay out the pages of their books. Illustration media or mixed-medium options were selected by each illustrator and supplies were purchased using the total course budget of $1875. The college print shop provided all printing services for the book products, but students were also encouraged to pursue other available self-publishing options after the end of the course.

After the course, students were asked for permission to ~~to~~ use their personal work, including written reflection, course evaluations, and final products, for research purposes. Responses were anonymized to the following reflection prompt: "Complete a 2-3-page critical reflection essay, describing the experience objectively (the where, who, what, when, why, and how) and personally (what was it like for you?). You will discuss your academic and personal progress during this experience as related to your major and career aspirations. You can describe a part of the process that was especially significant to you and explain

Table 2. Quotes about the students' experience.

Enjoyment

"There are truly no words to explain being able to successfully translate science into terms that interest children, through a book that was created in several weeks, and gift this cherished creation with those who have played a significant role in my education. After spending the afternoon in Salem Public Library to launch the new book surrounded by members of the community who came to support, educators who show up to support me and my work, and peers that I have formed bonds with (which feels like happened over night), all I can say is thank you Roanoke College. Thank you for this amazing experience of piecing together all of my education and foundation to create something that benefits the youth, educators, the community, and my future self."

"This class, as a whole, was a significant experience. I can genuinely say that I enjoyed this class far more than any other I have taken at Roanoke College. I loved the idea of being able to make a children's book, and getting to pick the topic. While daunting, it was the most fun I've had in a while."

Confidence

"I am so grateful for this experience; it is hard to find the words to describe just how thankful I am for this class. I definitely feel as though I have grown both academically and personally, in more ways than one. Overall, I can not recommend this class enough. I think this is an experience that everyone should have, because being able to say that hey, I wrote a book, on top of any other personal or academic progress they may make, is something to be proud of and excited about."

"This may term taught me so much about communication as I started with the base level audience of children. I feel I have just gained my first step to my career in environmental policy and law. This class gave me the utmost confidence to begin perfecting skills of scientific communication to diverse audiences, which I did not have before. This class also inspired me to try new things, even if they are uncomfortable, and push myself to succeed in these new things. This confidence in scientific communication and within myself as a student was the most significant takeaway from this class for me. The layout of this class starting from foundation all the way to a finished product, allowed so much time to digest and apply these new concepts even though this class was only three weeks long."

Helpful aspects of the course

"Definitely allowing us the time to work on our own and making us responsible for our own work."

"The days designated to having workshop classes geared towards showing us how to use things. For example, the days we did an adobe illustrator workshop, how to self publish, looking at different children's books to get an idea of style and format. Another aspect that was incredibly helpful is allowing us to have our own time to work on our books while doing some slight individual check ins."

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how this experience related to elements of your coursework and/or how it enhanced your knowledge of a particular concept." The responses were consolidated and examined for themes. Quotes that represented major themes are include below (Table 2).

230 3.3 Impact

A total of 14 children's picture books were created, with topics including the aurora borealis, photosynthesis, biomagnification, tardigrades, black holes, rainbow formation, and climate change (Fig. 3). Books were donated to the public library, 10+ primary school teachers, and the college's library. Students presented their books to the community through a student-planned book launch at the public library. Over 90 faculty, students, staff, and community members gathered to read the books and participate 235 in science experiments and crafts related to the book topics. Students reflected on the success and positive impact of the IL-course on their academic careers (Table 2).

4   Conclusions

This paper consists of two parts that assess the use of children's books in science communication. The *Farzana's Journey* project seems to have been a moderate success at achieving cross-cultural knowledge transfer. At a minimum, Bangladeshi students were exposed to local natural processes, environmental science concepts, and the history of coupled natural-human systems. The book increased public awareness of the natural environment and human adaptation that is characteristic in coastal Bangladesh with science and non-science communities in both Bangladesh and the U.S. The project also created new academic and societal partnerships with a variety of non-science collaborators during book development. But whether the project leaves a long-term impact on the target audience and project collaborators is less clear. It is likely that enduring engagement will be necessary to ensure the sustainability of the conversation, but achieving this will be a challenge given the international communication requirements and the end of the ISEE project. Nevertheless, book distribution by the university and the author will continue. The science storytelling IL-course exposed undergraduate students to alternative forms of writing and developed confidence in science communication of early-career scientists. Students expressed interest in future offerings of the course and community stakeholders voiced desire for sustained partnerships. The creation and use of children's books is a tangible and impactful means of science communication. By communicating through these multi-model forms, the broader impacts of research and complex scientific concepts can be expanded to previously unreached communities. We hope these projects serve as a template for the development of future children's books for broader impacts and pedagogical methods.

Sample availability.   *Farzana's Journey: A Bangladesh story of the water, land, and people*

Author contributions.   Chelsea Peters conceptualized, collected data, analyzed study data for this paper. She also wrote the manuscript.

Competing interests.   The author declare that they have no conflict of interest.

Ethical statement.   The data used in this study were recorded on a voluntary and completely anonymous basis. No Institutional Review Board waiver was obtained for data collected for Bangladeshi participants. Only legally authorized verbal informed consent from participants and representatives/parents/guardians verbal informed consent for minors were obtained for photographs. Photographs taken during the study were anonymized through blurred images. In the Roanoke College course, I was reviewed and approved by the Roanoke College Institutional Review Board (Project Number: 24003). Students were explicitly asked for permission to use student work for research purposes. Any personal information was treated as strictly confidential in accordance with the guidelines of Roanoke College.

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