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## **Establishing a Baseline of Science Communication Skills in an Undergraduate Environmental Science Course**

Rashmi Shivni

Christina Cline

Morgan Newport

Shupey Yuan

Heather E. Bergan-Roller

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## Establishing a Baseline of Science Communication Skills in an Undergraduate Environmental Science Course

--Manuscript Draft--

<b>Manuscript Number:</b>	STEM-D-20-00198R3	
<b>Full Title:</b>	Establishing a Baseline of Science Communication Skills in an Undergraduate Environmental Science Course	
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<b>Abstract:</b>	<p><b>Background</b></p> <p>Seminal reports, based on recommendations by educators, scientists, and in collaboration with students, have called for undergraduate curricula to engage students in some of the same practices as scientists—one of which is communicating science with a general, non-scientific audience (SciComm). Unfortunately, very little research has focused on helping students develop these skills. An important early step in creating effective and efficient curricula is understanding what baseline skills students have prior to instruction. Here, we used the Essential Elements for Effective Science Communication (EEES) framework to survey the SciComm skills of students in an environmental science course in which they had little SciComm training.</p> <p><b>Results</b></p> <p>Our analyses revealed that, despite not being given the framework, students included several of the 13 elements, especially those which were explicitly asked for in the assignment instructions. Students commonly targeted broad audiences composed of interested adults, aimed to increase the knowledge and awareness of their audience, and planned and executed remote projects using print on social media. Additionally, students demonstrated flexibility in their skills by slightly differing their choices depending on the context of the assignment, such as creating more engaging content than they had planned for.</p> <p><b>Conclusions</b></p> <p>The students exhibited several key baseline skills, even though they had minimal training on the best practices of SciComm; however, more support is required to help students become better communicators, and more work in different contexts may be beneficial to acquire additional perspectives on SciComm skills among a variety of science students. The few elements that were not well highlighted in the students' projects may not have been as intuitive to novice communicators. Thus, we provide recommendations for how educators can help their undergraduate science students develop valuable, prescribed SciComm skills. Some of these recommendations include helping students determine the right audience for their communication project, providing opportunities for students to try multiple media types, determining the type of language that is appropriate for the audience, and encouraging students to aim for a mix of communication objectives. With this guidance, educators can better prepare their students to become a more open and communicative generation of scientists and citizens.</p>	
<b>Corresponding Author:</b>	Heather Bergan-Roller Northern Illinois University UNITED STATES	
<b>Corresponding Author E-Mail:</b>	hroller@niu.edu	
<b>Corresponding Author Secondary Information:</b>		

<b>Corresponding Author's Institution:</b>	Northern Illinois University
<b>Corresponding Author's Secondary Institution:</b>	
<b>First Author:</b>	Rashmi Shivni
<b>First Author Secondary Information:</b>	
<b>Order of Authors:</b>	Rashmi Shivni
	Christina Cline
	Morgan Newport
	Shupey Yuan
	Heather Bergan-Roller
<b>Order of Authors Secondary Information:</b>	
<b>Response to Reviewers:</b>	<p>Thank you for your comments on our manuscript, "Establishing a Baseline of Science Communication Skills in an Undergraduate Environmental Science Course." We used this feedback to submit a refined, clean, and unblinded version of the manuscript.</p> <p>Below we define how we addressed each specific comment from the reviewers. Additionally, we checked for formatting and clarity as requested.</p> <p>Comments by Reviewer #4</p> <p>Comment. Reference Table 1 in Data Sources, since the demographics and amount of data collected is mixed in Table 1.</p> <p>Response. We added a reference to Table 1 and demographics to the data sources section (pg 12, line 232).</p> <p>Comment. Data source section: Include this statement if not already there: "...in order to provide insight into the possible influence that instruction can have on the students' demonstration of skills."</p> <p>Response. This phrase appears toward the end of the data source section (pg 12, line 235-238).</p> <p>Comment. Data source section: Clarify if instructor feedback was coded (and if not, why).</p> <p>Response. We added text to the end of the data source section to clarify that we did not analyze the individualized feedback given by the instructor after students submitted their plans as we focused on students' skills in aggregate. (pg 12, line 238-240).</p>
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<b>Question</b>	<b>Response</b>
Are you submitting to a Thematic Series?	No

1 **Establishing a Baseline of Science Communication Skills in an Undergraduate**  
2 **Environmental Science Course**

3

4 Rashmi Shivni<sup>a</sup>, Christina Cline<sup>a</sup>, Morgan Newport<sup>b</sup>, Shupey Yuan<sup>c</sup>, & Heather E. Bergan-  
5 Roller<sup>a\*</sup>

6

7 <sup>a</sup> *Department of Biological Sciences, Northern Illinois University, DeKalb, IL, U.S.A.;*

8 <sup>b</sup> *Weinberg College of Arts and Sciences, Northwestern University, Evanston, IL, U.S.A.;*

9 <sup>c</sup> *Department of Communication, Northern Illinois University, DeKalb, IL, U.S.A*

10

11 \*Corresponding author:  
12 Heather E. Bergan-Roller  
13 Department of Biological Sciences  
14 College of Liberal Arts and Sciences  
15 Northern Illinois University  
16 447 Montgomery Hall  
17 DeKalb, IL 60115  
18 815-753-7421  
19 hroller@niu.edu  
20 ORCID: 0000-0003-4580-7775

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## 1 **Abstract**

### 2 ***Background***

3 Seminal reports, based on recommendations by educators, scientists, and in collaboration with  
4 students, have called for undergraduate curricula to engage students in some of the same practices  
5 as scientists—one of which is communicating science with a general, non-scientific audience  
6 (SciComm). Unfortunately, very little research has focused on helping students develop these  
7 skills. An important early step in creating effective and efficient curricula is understanding what  
8 baseline skills students have prior to instruction. Here, we used the Essential Elements for  
9 Effective Science Communication (EEES) framework to survey the SciComm skills of students in  
10 an environmental science course in which they had little SciComm training.

### 11 ***Results***

12 Our analyses revealed that, despite not being given the framework, students included several of  
13 the 13 elements, especially those which were explicitly asked for in the assignment instructions.  
14 Students commonly targeted broad audiences composed of interested adults, aimed to increase the  
15 knowledge and awareness of their audience, and planned and executed remote projects using print  
16 on social media. Additionally, students demonstrated flexibility in their skills by slightly differing  
17 their choices depending on the context of the assignment, such as creating more engaging content  
18 than they had planned for.

### 19 ***Conclusions***

20 The students exhibited several key baseline skills, even though they had minimal training on the  
21 best practices of SciComm; however, more support is required to help students become better  
22 communicators, and more work in different contexts may be beneficial to acquire additional  
23 perspectives on SciComm skills among a variety of science students. The few elements that were  
24 not well highlighted in the students' projects may not have been as intuitive to novice

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25 communicators. Thus, we provide recommendations for how educators can help their  
26 undergraduate science students develop valuable, prescribed SciComm skills. Some of these  
27 recommendations include helping students determine the right audience for their communication  
28 project, providing opportunities for students to try multiple media types, determining the type of  
29 language that is appropriate for the audience, and encouraging students to aim for a mix of  
30 communication objectives. With this guidance, educators can better prepare their students to  
31 become a more open and communicative generation of scientists and citizens.

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**32 Introduction**

33 Scientists engage in a number of practices in their pursuit of understanding. Having students  
34 participate in these same practices — and as early as possible — is vital in fostering future  
35 generations of scientists and developing a scientifically literate society (ACARA, 2012; American  
36 Association for the Advancement of Science, 2011; American Chemical Society, 2015; Joint Task  
37 Force on Undergraduate Physics Programs, 2016; NGSS Lead States, 2013). One such practice is  
38 effective science communication.

39       Science communication can take many forms and is typically grouped into one of two types  
40 depending on the target audience – either a scientific audience or a non-scientific, general  
41 audience. While both types of audience-oriented communication are important for scientists and  
42 students, the focus of this study is on communicating science with non-experts (abbreviated as  
43 SciComm). In the current study, we describe SciComm as the use of appropriate media, messages,  
44 or activities to exchange information or viewpoints of science opinion or scientific information  
45 with non-experts. Depending on the goal of SciComm, it can be used for “fostering greater  
46 understanding of science and scientific methods or gaining greater insight into diverse public views  
47 and concerns about the science related to a contentious issue” (National Academies of Sciences,  
48 Engineering, 2017a, p. 14).

49       SciComm is an important scientific practice that benefits both scientists and the public.  
50 With effective SciComm, the public learns about foundational and modern scientific  
51 understanding that can guide personal and societal decisions. Additionally, the public can  
52 appreciate the credibility of scientists and the scientific process to trust scientific consensus even  
53 if the scientific content is not easily understood. Communication also allows scientists to recruit

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4 54 more people to engage with science as well as to collaborate and learn about issues in need of more  
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7 55 research.

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9 56 As such, scientists are being encouraged to engage in SciComm by their scientific  
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11 57 communities and the public (Cicerone, 2006; Department of Science and Technology, 2014;  
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14 58 European Commission, 2002; Jia & Liu, 2014; Leshner, 2007; National Research Council (U.S.).  
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16 59 Committee on Risk Perception and Communication, 1989; Royal Society (Great Britain) &  
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19 60 Bodmer, 1985), as well as combat the spread of misinformation (Scheufele & Krause, 2019).  
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21 61 Additionally, surveyed scientists report viewing themselves as important components in societal  
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24 62 decision-making (Besley & Nisbet, 2013) and commonly communicate with the public (Hamlyn  
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26 63 et al., 2015; Rainie et al., 2015). Moreover, support and focus for more effective SciComm across  
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29 64 STEM fields has grown. For example, researchers have investigated how to communicate  
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31 65 engineering issues and technological perspectives of science, such as genetic engineering (Blancke  
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34 66 et al., 2017; Kolodinsky, 2018), nanotechnology (Castellini et al., 2007), and artificial intelligence  
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36 67 (Nah et al., 2020)

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38 68 A pertinent example of scientists practicing effective SciComm was seen throughout the  
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41 69 severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic, where technical  
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44 70 experts in virology, epidemiology, data science, etc. took to social media and news media to  
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46 71 produce and disseminate evidence-based, accurate health protocols and information about the  
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49 72 novel coronavirus (American Society for Biochemistry and Molecular Biology (ASBMB), 2020).  
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51 73 During major events, such as the pandemic, scientists are responsible for an important role in  
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53 74 communicating emerging science with the public to ease fears, inform decisions, encourage  
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55 75 engagement, and give hope to the future.



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76           Because SciComm is an important practice for scientists, it is also essential that  
77 undergraduate science students engage with SciComm (Brownell et al., 2013b). All college  
78 students are expected to become proficient in interpersonal skills, including communication  
79 (National Academies of Sciences, Engineering, 2017b), and this is expressly true for students in  
80 STEM fields including biology (American Association for the Advancement of Science, 2011),  
81 chemistry (American Chemical Society, 2015), physics (Joint Task Force on Undergraduate  
82 Physics Programs, 2016), engineering (Eichhorn et al., 2010; Riemer, 2007), technology  
83 (Bielefeldt, 2014), and math (Saxe & Braddy, 2015).

84           Environmental science is an important context in which to study SciComm skills because  
85 it is transdisciplinary – at the intersection of biology, chemistry, physics, and social sciences.  
86 Seminal documents in biology (American Association for the Advancement of Science, 2011;  
87 Clemmons et al., 2020), chemistry (American Chemical Society, 2015), and physics (Joint Task  
88 Force on Undergraduate Physics Programs, 2016) have explicitly stated the need for helping  
89 students develop science communication skills. These seminal documents are being used across  
90 the sciences to inform curricula and are relevant in guiding curricula and research in environmental  
91 science education. Additionally, environmental science encompasses some vital topics relevant to  
92 all of society (e.g., climate change) and thus students learning about these important topics should  
93 also be learning about how to share that information with the public. Helping a wide range of  
94 students develop science communication skills may help students understand scientific concepts,  
95 the process of science, and the skills to engage with science after they are out of school regardless  
96 of whether they pursue science-related careers. These outcomes are essential in promoting the  
97 science literacy of our students and citizens.

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99 ***Conceptual Framework***

100 When aiming to help students develop skills, it is an important first step to operationalize those  
101 skills. In the context of undergraduate life sciences, the 2011 *Vision and Change* report broadly  
102 defined the skills, labeled as core competencies, students should develop in their undergraduate  
103 programs (AAAS, 2011). Clemmons et al. (2020) unpacked these core competencies into program-  
104 and course-level outcomes. Regarding communication, they define that students should be able to  
105 “share ideas, data, and findings with others clearly and accurately;” “Use appropriate language and  
106 style to communicate science effectively to targeted audiences (e.g., the general public, biology  
107 experts, collaborators in other disciplines);” and “Use a variety of modes to communicate science  
108 (e.g., oral, written, visual).” We expanded those definitions, using evidence-based practices and  
109 principles of science communication, to define the key elements of SciComm that are appropriate  
110 for undergraduate science students. The resulting Essential Elements for Effective Science  
111 Communication (EEES) framework (Wack et al., 2021) adapts skills and concepts from the  
112 literature (Besley et al., 2018; Mercer-Mapstone & Kuchel, 2017) and organizes them into four  
113 strategic categories of storytelling: “who,” “why,” “what,” and “how” (Figure 1). The full  
114 framework is available in Wack et al. (2021).

115 [INSERT FIGURE 1 HERE]

116 The framework is further broken down into 13 elements that are organized under these four  
117 categories, which we used to assess the students’ baseline SciComm skills. As shown in Figure 1,  
118 the four categories overlap to represent the interrelated nature of the 13 elements. In order to create  
119 effective and cohesive SciComm, each element must be considered in relation to the others.  
120 Briefly, we describe the categories and the elements they encompass below.

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121 The elements for *who* science students should communicate science with include  
122 identifying and understanding a suitable target audience and considering the levels of prior  
123 knowledge in the target audience. The elements for *why* science students should communicate  
124 science include identifying the purpose and intended outcome of the communication; this element  
125 is expanded upon by the important SciComm objectives defined by Besley et al. (2018)—including  
126 to increase knowledge and awareness, boost interest and excitement, listen and demonstrate  
127 openness, prove competence, reframe issues, impart shared values, and convey warmth and  
128 respect. Further, science students should understand the theories of science communication and  
129 why science communication is important. The elements of *what* science students should  
130 communicate include focusing on narrow, factual content and situating that content in a relevant  
131 context that is sensitive to social, political, and cultural factors. Finally, the elements for *how*  
132 science students should communicate science includes encouraging a two-way dialogue with the  
133 audience, promoting audience engagement with the science, using appropriate language, choosing  
134 a mode and platform to reach the target audience, and adding stylistic elements (e.g., humor,  
135 anecdotes, analogies, metaphors, rhetoric, imagery, narratives, and trying to appeal to multiple  
136 senses). See Wack et al., (2021) for the full framework.

137 The EEES framework was originally used to guide the development of a lesson for  
138 undergraduate biology students in an introductory lab (Wack et al., 2021). This framework is  
139 relevant here because, while biology is only a portion of the course context in this study (i.e.,  
140 environmental science), this framework was developed to be broadly applicable to any science  
141 students in undergraduate programs. Also, the framework describes the best practices for  
142 communicating science; through the lens of the backward design process (Wiggins & McTighe,

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143 2005), these best practices can be thought of as learning objectives. Therefore, it is appropriate to  
144 then assess student work with the same framework.

145

146 ***Baseline Skills***

147 After operationalizing competencies to provide a clear picture of what instructors should help their  
148 students attain, it is also important to understand what baseline skills students have at the start of  
149 a lesson; that way, a curriculum can be tailored to skim through honed skills and emphasize weaker  
150 skills. Identifying baseline skills, therefore, makes helping students learn these skills as efficiently  
151 and effectively as possible (Novak, 2010; Quitadamo & Kurtz, 2007). A similar argument is well-  
152 established in the context of helping students achieve conceptual understanding with the literature  
153 on *prior knowledge* (e.g., Ausubel, 2012; Bergan-Roller et al., 2018; Binder et al., 2019;  
154 Lazarowitz & Lieb, 2006; National Research Council (U.S.) & Committee on Programs for  
155 Advanced Study of Mathematics and Science in American High Schools., 2002; Tanner & Allen,  
156 2005; Upadhyay & DeFranco, 2008); however, assessing *skills* before a lesson is less commonly  
157 discussed in the literature, which we designate as *baseline skills*.

158         Assessment is required to identify students' skills, including their baseline skills. However,  
159 to our knowledge, there is very little literature that provides insight into the assessment of  
160 undergraduate science students on science communication skills. Kulgemeyer and Schecker  
161 (2013) examined how students communicate science in the limited context of older secondary  
162 students communicating physics phenomena to younger students. In another study, Kulgemeyer  
163 (2018) went further by testing older secondary students on audience-oriented SciComm best  
164 practices and found that those with more SciComm experience, or more developed baseline skills,  
165 were better at discerning an audience's needs for particular SciComm content than students who

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166 had less experience with SciComm but were quite knowledgeable about the content. Other studies  
167 related to students and SciComm have measured application of SciComm knowledge with closed-  
168 response quiz questions (Wack et al., 2021), perceptions and confidence in communicating science  
169 (Brownell et al., 2013a), the value of SciComm (Edmondston et al., 2010a), and perceptions of  
170 SciComm skills (Yeoman et al., 2011); but they have not assessed how students demonstrate  
171 SciComm skills. More work needs to be done to assess how students communicate science in a  
172 variety of contexts (e.g., disciplines, audiences, level of the student) in order to establish a  
173 generalized baseline of skills from which to build an effective curriculum.

In this descriptive study, we surveyed baseline SciComm skills of students in an  
undergraduate environmental science course in order to inform instructors and curriculum  
designers on how to help similar science students develop SciComm skills. We took an  
exploratory, qualitative approach to investigate the following research questions:

- RQ1- How did these students demonstrate their SciComm skills according to the EEES  
framework?
- RQ2- How did the way these students planned their SciComm compare to how they  
executed their SciComm projects?
- RQ3- Did instructions influence the SciComm skills that these students demonstrated?

**Methods**

We conducted an exploratory case study according to VanWynsberghe and Khan (2007); our unit  
of analysis was students' SciComm skills and our case was one undergraduate environmental  
science course in which the students demonstrated their baseline skills with a project that included  
planning and executing a SciComm product.

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189 ***Study Context***

190 The study was conducted at a large four-year, doctoral-granting, regional comprehensive  
191 university in the Midwestern United States with students enrolled in an environmental science  
192 course. This course focused on the functioning of ecosystems, the patterns of biological diversity,  
193 the processes that influence those patterns over space and time, and how human activities can  
194 disrupt those processes. The course included a SciComm project, which we used for this research;  
195 however, SciComm was not a focus of the course. Students did not receive formal training on the  
196 underlying theories or practices of SciComm relevant to the EEES framework or otherwise; and  
197 we did not gather background information on whether students had knowledge from elsewhere to  
198 apply to their SciComm projects. We saw this as a unique opportunity to obtain a baseline of  
199 SciComm skills.

200 Study participants were recruited by one author attending a class period early in the  
201 semester, describing the study, and asking for their explicit consent. The entire class was given the  
202 opportunity to participate in the study, of which 32 (65%) consented. Students were assigned to  
203 plan and execute SciComm products, which we analyzed for this research. From the consenting  
204 students, 27 plans and 21 products were available for this research. All names listed herein are  
205 pseudonyms. Demographics for each of these populations are shown in Table 1 and the result show  
206 that they are equivalent. Generally, the samples consisted of more females than males. Most of the  
207 students were White/non-Hispanic, juniors, and 18-25 years old. About one-third of the students  
208 were first-generation college students and two-thirds were transfer students. Cumulative GPAs  
209 averaged 3.1 to 3.3 (with standard deviations of 0.9). The demographics of these students are  
210 typical for the university and major, as well as for undergraduate biology students throughout the

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211 U.S.—as compared to data from the U.S. Department of Education’s National Center for  
212 Education Statistics (Data USA, 2018).

213  
214 **Table 1.** *Demographic information from the consenting students and their coursework (plans and*  
215 *products) included in this research.*

	Consenting	Plans	Products
n	32	27	21
Females	19	18	14
Males	13	9	7
18-21 years	10	10	7
22-25 years	14	12	9
26-30 years	6	4	4
31-40 years	2	1	1
White/Non-Hispanic	28	24	18
Other race/ethnicity	4	3	3
Freshman	1	1	1
Sophomores	6	5	3
Juniors	17	14	12
Seniors	6	5	4
Post-bachelors	2	2	1
First generation	11	9	7
Transfers	21	18	14
Cum. GPA (SD)	3.1 (0.9)	3.2 (1.0)	3.3 (0.9)

216 *Numbers represent students in each category of consenting students and the student plans and*  
217 *products that were available for this research.*

219 **Assignment**

220 As a regular part of the course, students were assigned a project to communicate science with a  
221 general, non-scientific audience. Their projects included having students submit a plan to the  
222 instructor, who gave individual feedback, and then execute their plan in what we call their product.

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223 Assignment instructions and rubric, which were provided to the students when the project was  
224 assigned, are available in supplemental materials S1 and S2, respectively. Students were given  
225 creative freedom to communicate scientific content—using any means such as presentations,  
226 social media, and blogging—to a specific audience of their choosing. The instructions required the  
227 students to interact with an audience from the public. Though the assignment was developed solely  
228 by the instructor (the researchers and the framework were not a part of the assignment design),  
229 there was some overlap with the EEES framework that was explicitly mentioned in the assignment.

230

231 ***Data Sources***

232 Several course artifacts and student demographics were collected for this research (Table 1).  
233 Students’ plans and products were collected to identify which elements of the framework they  
234 included as evidence of their baseline skills. The students’ final products are available through the  
235 figshare data repository (Bergan-Roller & Yuan, 2021). Additionally, we collected the assignment  
236 instructions and rubric (supplemental materials S1 and S2) to identify which elements of the  
237 framework were included in order to provide insight into the possible influence that instruction  
238 can have on the students’ demonstration of skills. However, we did not analyze the individualized  
239 feedback given by the instructor after students submitted their plans as we focused on students’  
240 skills in aggregate.

241

242 ***Analysis***

243 The plans, products, assignment instructions, and rubric were imported into qualitative software  
244 (NVIVO) and analyzed using content analysis which describes the themes in artifacts such as  
245 coursework (Neuendorf, 2017). First, we conducted *a priori* thematic analysis by coding for the



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246 presence or absence of each of the elements of the EEES framework (codebook provided in  
247 Supplemental Materials S3). Three elements were not observable in the products (purpose, prior  
248 knowledge, and theory). After the presence of elements was identified, student plans and products  
249 underwent further thematic analysis to identify themes in how students addressed the elements of  
250 the framework (Braun & Clarke, 2006). An excerpt of an example product is presented in Figure  
251 2 with a description of how it was coded in the figure caption. To ensure the reliability of the  
252 codes, two of the authors co-coded all the data. The initial agreement was 83%. All dissimilar  
253 codes were discussed to a consensus, and the codebook was revised to clarify the codes. The final  
254 codebook is available in supplemental materials S3.

[INSERT FIGURE 2 HERE]

256 Most students completed the assignment individually; however, when a pair worked  
257 together on the assignment, the project artifacts (plans and products) were treated as single  
258 artifacts. This work was conducted with prior approval from the institutional review board  
259 (#HS17-0259).

260

261 **Results**

262 Below we describe if and how the elements of the EEES framework appeared in students' projects  
263 (i.e., plans and products). Later, in the discussion, we interpret these descriptions to characterize  
264 these students' baseline SciComm skills. Additionally, we examined the project instructions for  
265 alignment with the EEES framework as an indication of how instruction may be able to influence  
266 the development of SciComm skills in undergraduate science students.

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**268 *Presence of SciComm Elements***

269 The elements of SciComm that students described in their plans were similar to those demonstrated  
270 in their products, but there were a few key differences (Table 2). Students described a similar  
271 number of elements in their plans ( $8.0 \pm 1.0$ ) as they demonstrated in their products ( $8.1 \pm 0.9$ ),  
272 despite all 13 elements being observable in plans but only 10 being observable in products. Most  
273 to all the students described the elements of content, platform, mode, audience, dialogue, and  
274 engagement in their plans and demonstrated these elements in their products. Additionally, plans  
275 and products were similar in how few students included the elements of context and style.  
276 Dissimilarities existed in the number of students who described intending to use language in the  
277 plans and who demonstrated language in the products. Appeal was also present in more products  
278 than plans. Most students described a purpose in their plans while less than a third described  
279 considering the prior knowledge of their audience or the theoretical rationale for their decisions.

280

281

282 **Table 2.** *Presence of Essential Elements for Effective SciComm in student projects out of 27 plans*  
 283 *and 21 products.*

	<b>Element</b>	<b>Plans <i>n</i> (%)</b>	<b>Products <i>n</i> (%)</b>
Instructions	Content	27 (100%)	21 (100%)
	Platform	27 (100%)	21 (100%)
	Mode	27 (100%)	21 (100%)
	Audience	27 (100%)	21 (100%)
	Purpose	23 (85%)	NA
	Dialogue	27 (100%)	21 (100%)
	Engagement	27 (100%)	20 (95%)
Rubric	Language	1 (4%)	21 (100%)
	Appeal	9 (33%)	15 (71%)
	Context	4 (15%)	5 (24%)
	Style	3 (11%)	6 (29%)
	Prior knowledge	8 (30%)	NA
	Theory	7 (26%)	NA

284  
 285 *Elements that were not observable are denoted with NA. Brackets in the left margin indicate*  
 286 *which elements were explicitly addressed in the assignment instructions and rubric.*

287  
 288 The instructor’s assignment instructions and rubric included some of the EEES framework  
 289 elements even though the instructor did not have the framework and the researchers did not direct  
 290 the instructor on assignment design prior to the semester. Nevertheless, we compared what  
 291 elements appeared in the assignment instructions and rubric with the elements students

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292 demonstrated in their projects to provide insight into the effect that instruction can have on the  
293 students' demonstration of skills (as further explained in the discussion). Elements that were  
294 explicitly mentioned in the assignment instructions were described in plans and demonstrated in  
295 products by most students (Table 2); fewer students described elements in their plans that were  
296 only present in the rubric, while many more students demonstrated these rubric-only elements in  
297 their products. Elements that were not explicitly asked for in either the instructions or rubric were  
298 present in the fewest student plans and products.

300 ***Themes for How Students Presented SciComm Elements***

301 Beyond if the elements were present in the students' projects, we analyzed *how* the students  
302 presented these elements. We organized the results below into the four strategic categories to  
303 which the elements belong in the framework.

304 *Who did students communicate with?*

306 ***Audience.*** The students defined their audiences through categories of specificity, age, and interest  
307 (Table 3). More than half the students targeted both a specific audience in conjunction with a  
308 general audience in their plans and products. For example, Wells wrote,

309 *“My target audience would be people that work outdoors first and foremost, as this issue*  
310 *would affect them the most from a health perspective. Otherwise, I think the environmental*  
311 *aspect of the issue affects everyone and anyone, so I would want to spread that information*  
312 *to as many people as possible.”*

313 When specifying their audience, the students described age and interest. More students  
314 targeted adults over young adults or children. In the plans, about half of the students aimed for an

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315 audience with identified interest or non-interest in the scientific content that they intended to  
316 communicate. Of the 15 plans that addressed the interest of the audience, most targeted an audience  
317 with an interest in the subject. A few of the students explicitly sought out an audience who were  
318 not already interested in the scientific content (Table 3). For example, Bellamy wrote,

*“I hope to reach people that are not extremely in tune with the environment.”*

320 Two out of the 27 plans (Bellamy and Echo) described wanting to address an audience that  
321 included both interested and uninterested members. The interest of the audience was not  
322 observable in the final products as this work focused on the students and their work, not the  
323 students’ audiences.

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325 **Table 3.** *Thematic categories and subcategories of students’ target audiences out of 27 plans and*  
 326 *21 products.*

<b>Audience</b>	<b>Plans n (%)</b>	<b>Products n (%)</b>
Specificity	27 (100%)	21 (100%)
Specific	25 (93%)	19 (90%)
General	18 (67%)	15 (71%)
Age	19 (70%)	9 (43%)
Adult	11 (58%)	5 (56%)
Young Adult	8 (42%)	2 (22%)
Child	5 (26%)	3 (33%)
Interest	15 (56%)	NA
Interested	13 (87%)	NA
Uninterested	4 (27%)	NA

327 *Numbers represent the number of students that defined their audience with each category (i.e.,*  
 328 *specificity, age, or interest) and subcategory. Percentages represent the percent of students that*  
 329 *described their audience with the subcategory (e.g., adult) out of the number of students that*  
 330 *defined their audience within the broader category (e.g., age).*

331  
 332 **Prior Knowledge.** The students approached the element of prior knowledge by collecting and  
 333 sometimes using information about their audiences’ understanding to influence their projects.  
 334 Eight students (30%) planned to collect information on the prior knowledge of their audience. For  
 335 example, Raven wrote,

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336            *“I plan to ask the children about their own thoughts on the subject, of what they already*  
337            *know about sharks and how they perceive them, why they think sharks are important and*  
338            *helpful to the ecosystem, and what they can do to help preserve the shark's habitat.”*

339            Raven planned to move forward with her presentation irrespective of the children’s input.

340            Four students (15%) described planning to use the prior knowledge information they gathered by  
341            adapting their products accordingly. For example, Niylah wrote that she would (emphasis is ours):

342            *“create a survey with a mixture of multiple-choice and open-ended/extended-response*  
343            *questions to gauge the public’s knowledge on recycling (what is recyclable, where do these*  
344            *materials go after they are recycled, etc.) and what questions they have about*  
345            *recycling...Create easy-to-understand and visually appealing infographics on recycling*  
346            ***based on survey results...in an attempt to address and clarify common misconceptions.”***

347  
348            *Why did the students communicate this science?*

349            ***Purpose: Communication Objectives.*** We examined how students described the purpose of their  
350            projects in their plans through the lens of Besley’s work that defines important science  
351            communication objectives (Besley et al., 2018) (Table 4). Several students intuitively developed  
352            their project’s purpose and described between zero and four objectives with two objectives being  
353            the most common (9 students, 33%). The objective to increase knowledge or awareness was the  
354            most common followed by the explicit goal to cause their audience to act, which is not a part of  
355            the Besley framework of objectives. For instance, Wells planned to create a public service  
356            announcement to show the effects of climate change on human health. His call to action was to  
357            help people slow the buildup of greenhouse gases from everyday changes, such as providing  
358            examples of cleaner forms of transportation and energy use.

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359 **Table 4.** *Science communication objectives students reported as the purpose of their projects out*  
360 *of 27 plans analyzed through the work by Besley et al., (2018).*

<b>Purpose objective</b>	<b>Plans n (%)</b>
Increase knowledge and awareness	21 (78%)
Other: take action*	12 (44%)
Boost interest and excitement	10 (37%)
Listen and demonstrate openness	7 (26%)
Reframe issue	4 (15%)
Convey competence	2 (7%)
Convey warmth and respect	2 (7%)
Convey shared values	2 (7%)

361 *\*Not present in the Besley framework but emerged from our data. Objectives were not observable*  
362 *in products.*

363  
364 The next most common objectives were to boost interest and excitement, as well as listen  
365 and demonstrate openness. For example, Echo demonstrated openness by starting a discussion on  
366 Facebook—within her circle of family and friends—to understand different points of view on  
367 climate change. She stated that she would “respond politely with facts, but in a way where [my  
368 peers] don’t feel attacked.” Few students included any one of the other four objectives.

369  
370 **Theory.** For the students that included some element of theory (7 plans, 26%), their rationalization  
371 for why they made certain decisions did not align with science communication theory or evidence-  
372 based practices. For example, Clarke said she wanted to make the project entertaining so that the



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373 audience would be more likely to remember the information, and Anya chose college students as  
374 a target audience because she believed that people who go to college are more passionate and  
375 generally interested in changing the world. These explanations seemed to be based on their  
376 interpretations of how learning works and how education increases interest, respectively, but not  
377 necessarily based on the literature.

378 Another student, Madi, chose a target audience of high school students because “They are  
379 mature enough to instill the information being taught, but just as immature enough to refuse to  
380 accept it.” Her rationale stems from, as she explained, her upbringing in a household with parents  
381 who were teachers. Though not established in the literature on teaching nor SciComm, this student  
382 made a decision about her audience based on descriptions from her parents—her authority figures.

383  
384 *What did the students communicate?*

385 **Content.** We analyzed the scientific content of the students’ projects regarding what components  
386 they included and what topics they focused on (Table 5). Most to all students incorporated a human  
387 component to their projects and several included a biological (non-human) component. The human  
388 component was labeled if the plans and products presented anything related to human involvement.  
389 For instance, climate change would fall into this category only if a student explicitly talked about  
390 human roles in either causing climate change or how their actions could mitigate the effects of  
391 climate change. There had to be some language explicitly relating to people and not just assumed  
392 human involvement. For the biological component, the projects had to explicitly reference non-  
393 human biological species. For example, a student working on a climate change SciComm project  
394 would need to mention the effects on other species than humans. Components relating to earth  
395 sciences (e.g., weather and oil spills) were present but infrequent (four or fewer students). The

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396 students focused on topics that were covered at other times during the course at relatively equal  
397 proportions with an ecological topic being slightly more popular than sustainability or climate  
398 change.

399 **Table 5.** *Thematic categories and subcategories of content out of 27 plans and 21 products.*

<b>Content</b>	<b>Plans n (%)</b>	<b>Products n (%)</b>
Components		
Human	27 (100%)	20 (95%)
Biological	13 (48%)	15 (71%)
Topics		
Ecology	10 (37%)	10 (48%)
Sustainability	9 (33%)	6 (29%)
Climate Change	6 (22%)	6 (29%)
Other	2 (7%)	NA

400 *Numbers represent the number of students that included a biological or human component or*  
401 *focused on the listed topics.*

402 **Context.** Some of the students considered the social, political, and/or cultural context of the  
403 scientific information (4 out of 27 plans, 5 out of 21 products). Although there were too few of  
404 these students to decipher themes within context, examples included describing the culture of  
405 coastal fishermen in relation to overfishing issues (Harper), and that the ability to choose foods  
406 from sustainable farming practices may be impacted by socioeconomic status (Lincoln).

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407 *How did the students communicate science?*

408 **Dialogue.** Dialogue pertains to any conversation between the student presenter and the audience.  
 409 Conversation could be on any subject including on scientific content being communicated or other  
 410 topics. Student plans and products were analyzed for the element of dialogue in two ways: the  
 411 direction and level of dialogue. For the direction of dialogue, all students talked to their audience  
 412 and most students also received input from their audience (Table 6).

413  
 414 **Table 6.** *Thematic categories of how students communicated, including dialogue, engagement,*  
 415 *language, mode, and platform out of 27 plans and 21 products.*

Element	Theme	Plans <i>n</i> (%)	Products <i>n</i> (%)
<b>Dialogue</b>	Direction		
	Student to audience only	7 (30%)	2 (10%)
	Audience to student only	0	0
	Both	20 (74%)	19 (90%)
	Level		
	Low	7 (26%)	2 (10%)
	Medium	16 (59%)	7 (33%)
	High	4 (15%)	12 (57%)
<b>Engagem ent</b>	Type		
	Passive	23 (85%)	11 (52%)
	Questioning		
	From student	9 (33%)	14 (67%)
	From audience	14 (52%)	18 (86%)
	Active	1 (4%)	1 (5%)
	Ambiguous	3 (11%)	NA

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	Level		
	Low	8 (30%)	4 (19%)
	Medium	12 (44%)	9 (43%)
	High	7 (26%)	8 (38%)
<b>Language</b>	Jargon		
	Use	0	8 (38%)
	Not use	1 (4%)	13 (62%)
	Formality		
	Only formal	0	4 (19%)
	Only informal	0	8 (38%)
	Mixed	0	9 (43%)
<b>Mode and Platform</b>	Location		
	Remote	19 (70%)	14 (67%)
	In person	9 (33%)	8 (38%)
	Media Type		
	Print	7 (26%)	13 (62%)
	Audio	13 (48%)	2 (10%)
	Video	10 (37%)	6 (29%)
	Social Media		
	Use	19 (70%)	14 (67%)
	Not use	8 (30%)	6 (33%)

---

416 *Numbers represent the number of students under each subcategory.*

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418 The level of dialogue indicated how much dialogue was planned or occurred. Low dialogue

419 was when only one direction of communication was planned or occurred (e.g., student

420 communicating to the audience only). Fewer students executed low dialogue than described low

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421 dialogue in their plans (Table 6). Medium dialogue was when both directions of dialogue were  
422 planned or occurred, but one direction was much more prevalent than the other (e.g., a presentation  
423 with a brief question-and-answer (Q&A) session). Over half of the students described medium  
424 dialogue in their plans while only about a third executed dialogue at this level (Table 6). High  
425 dialogue was when both directions of dialogue were planned or occurred frequently and throughout  
426 the communication. The fewest number of students planned high dialogue although the largest  
427 number of students executed high dialogue (Table 6).

428  
429 **Engagement.** Engagement pertains to how the audience engages with the science. Student plans  
430 and products were analyzed for the element of engagement in two ways: the type and level of  
431 engagement. Most of the students passively engaged their audience by having the audience listen  
432 and/or observe the presentation (Table 6). Engagement commonly took the form of asking the  
433 audience specific questions about the science or allowing for questions or comments from the  
434 audience. Only 1 out of 27 students planned to actively engage their audience with the science by  
435 having them play a board game on migration and go bird watching (Indra). Only 1 out of 21  
436 students executed active engagement by having students identify rocks with a game (Lexa). A few  
437 of the students mentioned engaging their audience with the science but did not further describe  
438 how they planned to do so (coded as ambiguous) (Table 6).

439         The level of engagement indicated how much the student planned or facilitated the  
440 audience to engage with the science. Low engagement was when the student presented to the  
441 audience who only viewed or listened nearly the entire time. A third of students planned to engage  
442 their audience at a low level but a slightly lower percentage executed low-level engagement (Table  
443 6). Medium engagement was when the student presented and the audience viewed and/or listened  
444 most of the time but there were some other types of engagement, commonly as questions between

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445 the audience and student. Most students planned and executed medium-level engagement (Table  
6). High engagement was when the student facilitated active and/or frequent engagement between  
the audience and the science, such as the audience answering frequent specific questions and  
modeling or observing a scientific phenomenon (e.g., bird watching or the rock game). The fewest  
students planned high-level engagement; however, more of the students executed high engagement  
(Table 6).

**Language.** We coded language for whether students used jargon and the formality of their  
language (Table 6). Only 1 out of the 27 students (Abby) described in her plans what language she  
would use by “avoiding jargon.” More students omitted jargon from their products than included  
jargon. More students used informal language when communicating science than formal language,  
or they used a mix of formal and informal rhetoric.

**Mode & Platform.** The students approached the elements of mode and platform in terms of  
location, use of media types, and use of social media (Table 6). More of the students had projects  
that were remote from their audience than in-person. A few of the students planned projects that  
involved both remote and in-person portions. In-person projects were commonly set in a  
classroom. As for media types, most students used print media (e.g., the Twitter Q&A and  
conversations in Figure 2) in their final products and several students used multiple types of media  
(Table 6). While many of the 27 students planned to do audio-based projects such as podcasts,  
only 2 out of 21 executed that plan. Regarding where to put their SciComm, most students included  
social media, which included sites like Facebook, Twitter, and YouTube (Table 6).

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468 *Appeal & Style.* The students appealed to their audiences’ senses primarily with visuals including  
469 PowerPoint slides, photos, artwork, and charts. Some of the students used stylistic elements to  
470 present scientific information. For example, Bellamy included humor and satire by dressing up in  
471 a penguin suit and advertising to “kill the penguins.” Gaia employed narration and described her  
472 adventures at the local farmer’s market.

473

474 **Discussion**

475 To tailor a curriculum to be meaningful and authentic, educators and education researchers need  
476 to first define learning outcomes that align with professional, scientific practice and then use those  
477 definitions to assess students' baseline skills, including for SciComm. Then, the curriculum can be  
478 built upon this solid foundation. Here, we provided a rich description of the baseline SciComm  
479 skills of students in an undergraduate environmental science course. Overall, our results showed  
480 that these undergraduate students are on their way to being effective science communicators and  
481 have room to develop these skills further with proper curricular support. We next interpret that  
482 description to guide instructors on how to help students develop important SciComm skills.

483 Students demonstrated their skills consistently, between their plans and products, in many  
484 ways including identifying their audience and focusing on factual content. However, there were a  
485 few notable exceptions. Students planned primarily one-way dialogue (e.g., talking at a class) but  
486 executed frequent two-way dialogue (e.g., played a game with the audience) throughout their  
487 SciComm; this switch to more interaction from planning to execution was similar to how students  
488 engaged their audiences with the science. But not all skills listed in the framework were observed  
489 in the students’ work, which provides instructors the room to give students a wide variety of  
490 opportunities and circumstances to demonstrate, practice, and develop their SciComm skills.

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491 Furthermore, the results showed that it is important to recognize the value of the instruction  
492 given by the instructor, which affected the types of skills students demonstrated. The students  
493 demonstrated most of the elements in their plans and products that aligned with what was asked  
494 of them in the instructions. This suggests that students would benefit from explicit SciComm  
495 instruction and training on effective SciComm to develop their SciComm skills in the context of  
496 their science coursework.

497  
498 *Pedagogical and curricular recommendations for integrating SciComm into science courses*

499 Below, we take a fine-grain view of the SciComm skills these students demonstrated and make  
500 recommendations on how instructors and curriculum can build off this baseline to effectively help  
501 science students develop their SciComm skills.

502  
503 *With whom to communicate science*

504 Help students identify a narrow audience. Our findings showed that the students commonly  
505 described a specific population but then also described trying to reach a broader audience. Students  
506 may need help recognizing that fostering quality communication with a small and specific  
507 audience is more effective than just exposing their SciComm to large quantities of people (Mercer-  
508 Mapstone & Kuchel, 2017).

509 Help students understand their audience. Here, about a third of the students considered the  
510 prior knowledge of their audience and fewer used it to influence their products. Similarly, about  
511 half of the students did not describe whether they thought their audience was explicitly interested  
512 or not interested in the subject. A presenter must acknowledge and understand what their audience  
513 already knows (i.e., prior knowledge) and what the audience is interested in to increase knowledge



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514 (Ausubel, 2012; Novak, 2010; Vosniadou, 2013), which was the most commonly stated purpose  
515 objective. This is true whether the setting is a classroom between an instructor and students or on  
516 a public stage such as with these environmental science students and their target audiences.

517

518 *Why communicate science*

519 Introduce students to the theories that make for effective SciComm. Despite not being asked to,  
520 some of the students described their rationale behind why their project would effectively  
521 communicate science with the public (theory element). However, these explanations seemed to be  
522 based on intuition, and were lacking operational description, which are often ineffective and can  
523 be harmful to the public’s perceptions of science (Scheufele, 2013). Therefore, instructors may  
524 consider introducing SciComm via its theoretical underpinnings to help students better understand  
525 the need for developing such skills.

526 Encourage students to aim for diverse communication objectives. Here, many students  
527 intuitively aimed to increase knowledge and awareness. Similarly, scientists focus more on this  
528 traditional knowledge-based objective than other equally important objectives (Besley et al.,  
529 2018). Nevertheless, scientists, and thus science students, need to aim beyond just increasing  
530 knowledge and awareness as many other objectives are key to effective SciComm (Besley et al.,  
531 2018). Specifically, appropriate for science students are the objectives of boosting interest and  
532 excitement, conveying warmth and respect, conveying shared values, and listening and  
533 demonstrating openness (Figure 1). Further, having an audience take action is an assumed, ultimate  
534 goal of communication (Besley et al., 2018); here, about half of the students’ plans made this goal  
535 explicit. More work is needed to know if students are thinking about an ultimate goal for their

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536 SciComm. Together, our work suggests that the curriculum should provide support to help students  
537 identify their broader goals and specific objectives for SciComm.

538  
539 *How to communicate science*

540 Give students practice with multiple media types. Here, many students planned to use audio and  
541 video, but then executed their SciComm with print media. A recent report concluded that Gen Z  
542 (people born between the mid-1990s and the mid-2000s) prefer video over print for learning  
543 whereas Millennials (people born in the early 1980s to mid-1990s) prefer print (Pearson Education  
544 Inc., 2018). The students studied here were composed of approximately 75% Gen Z and 20%  
545 Millennials. One explanation for our results could be that the students had ambitions to increase  
546 the knowledge and awareness of their audience using a medium which they themselves prefer and  
547 commonly consume (video) but potentially experienced logistical constraints that directed them to  
548 a simpler media (print) that could still reach a large audience (e.g., Lincoln’s switch from podcast  
549 to print). Scientists have increasingly connected with the public, using print, audio, and video  
550 remotely due to the SARS-CoV-2 pandemic (ASBMB, 2020). Therefore, students need practice  
551 with a variety of media types, especially on a variety of platforms as communication with the  
552 public evolves.

553  
554 *Example curricula*

555 There are a few published examples of integrated SciComm and science curriculum that may help  
556 science students develop their SciComm skills. These are organized either as whole courses or  
557 modules within science courses. Examples of whole courses include an undergraduate  
558 neuroimmunology and writing course (Brownell et al., 2013a) and a biotech and SciComm course

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559 (Edmondston et al., 2010a, 2010b). Examples of the modular approach have been documented in  
560 the contexts of junior high school (Spektor-Levy et al., 2008, 2009), undergraduate physics (Arion,  
561 2016; Arion et al., 2018), mid-level undergraduate biology, physics, and chemistry (Mercer-  
562 Mapstone & Kuchel, 2016), and upper-level undergraduate biology (Yeoman et al., 2011).  
563 Additionally, we applied the EEES framework to develop and assess a module for introductory  
564 undergraduate biology students (Wack et al., 2021). These curricula may be excellent sources for  
565 instructors looking for guidance on how to help their students develop SciComm skills.

566

567 *Assessment and Feedback*

568 Vital components of learning are assessment and feedback. Assessment of students should be  
569 based on the learning goals and objectives that instructors make explicit at the beginning of any  
570 lesson (Wiggins & McTighe, 2005) and thus can vary considerably. The options to assess  
571 SciComm lessons include what others in the literature have done, including using a closed-  
572 response quiz where students apply their knowledge of SciComm (Wack et al., 2021); asking for  
573 students to report on their gained skills (Yeoman et al., 2011); measuring perceptions, value, and  
574 confidence in communicating science (Brownell et al., 2013a; Edmondston et al., 2010a); and  
575 characterizing the skills students demonstrate as we have done here. Additional assessment could  
576 include input from the audience to gauge the effectiveness of the communication. These  
577 assessment options can be used to provide feedback to students so that they may reflect on their  
578 performance and how they may perform better in the future—an important step in developing  
579 lasting skills.

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581 ***Limitations and Future Directions***

582 We recognize the limitations of this research and suggest how future studies could augment this  
583 work. For instance, we intentionally omitted giving the students the framework in the instructions  
584 and rubric so that we could observe a baseline of SciComm skills. Future work should investigate  
585 how providing different scaffolds, or support such as the framework, affects students' SciComm  
586 skills.

587 By using content analysis of student work, we were able to provide rich descriptions of  
588 students' SciComm skills. Future work should use student interviews and reflective journaling to  
589 triangulate evidence on SciComm skills. When only a few students described a certain element, it  
590 reduced our ability to establish themes for how students commonly address an element and limits  
591 the generalizability of the results. Nevertheless, our findings on these elements provide some  
592 anecdotal examples of what one might expect from their students or study population.

593 Many of the elements of SciComm are intertwined, as are best practices for SciComm. For  
594 example, the audience one targets (e.g., young children) will impact the platform they choose (e.g.,  
595 a classroom, not Twitter). These interconnections led to occasional overlap in our coding (e.g.,  
596 engagement/dialogue, types/levels) and results could be influencing other results. Nonetheless,  
597 descriptions of each element provided a comprehensive survey of the students' baseline skills and  
598 thus were important to characterize individually.

599 We recognize that this is just one class in one context; much more work needs to be done  
600 in a variety of contexts, and separate results based on student demographics, to gain additional  
601 perspectives on undergraduate life science students' baseline SciComm skills. For example,  
602 repeating this study with larger groups of students in more disciplines would improve statistical  
603 strength; additionally, larger samples would allow for testing the effects of age or experience on

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604 outcomes so that these results may be extrapolated to other institutions and other disciplinary  
605 contexts across STEM fields.

606

607 **Conclusions**

608 SciComm is an important scientific practice for which undergraduate science students should  
609 develop skills. To effectively help students develop these skills, it is important to understand what  
610 baseline skills students have. Here, we used the EEES framework to explore the SciComm skills  
611 students in an environmental science course demonstrated with little training. Despite not being  
612 given the framework, students included several of the 13 elements, especially those which were  
613 explicitly asked for in the assignment instructions. Students exhibited SciComm skills similar to  
614 scientists who are novice in SciComm but showed promising development by following many of  
615 the instructions and refining their work from planning to execution. Together with the  
616 recommendations we make for how instructors can use these findings, a curriculum that is  
617 grounded in effective science communication can help undergraduate science students develop  
618 meaningful SciComm skills.

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**619 List of Abbreviations**

620 EEES – Elements for Effective Science Communication framework

621 Plans – written documents students submitted to plan their SciComm

622 Products – evidence students submitted of their executed SciComm

623 Projects – the combination of students’ plans and products

624 Q&A – question and answer

625 SARS-CoV 2 – severe acute respiratory syndrome coronavirus 2

626 SciComm – communicating science with non-experts

627

**628 Declarations**

**629 *Availability of Data and Materials***

630 The datasets used and/or analyzed during the current study are available from the corresponding

631 author on reasonable request. Student products, specifically, are available in the figshare

632 repository, <https://doi.org/10.6084/m9.figshare.14544072> (Bergan-Roller & Yuan, 2021).

633

**634 *Competing Interests***

635 The authors declare that they have no competing interests.

636

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643

644 *Authors' Contributions*

645 RS analyzed and interpreted the data and substantively revised the manuscript. CC acquired,  
646 analyzed, and interpreted the data and wrote portions of the manuscript. MN analyzed, and  
647 interpreted the data and wrote portions of the manuscript. SY helped conceive the work, and  
648 substantively wrote and revised the manuscript. HBR helped conceive and design the work,  
649 analyzed and interpreted the data, and substantively wrote and revised the manuscript. All authors  
650 read and approved the final manuscript.

651

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**841 Figure Captions**

**842 Figure 1.** Overview of the Essential Elements for Effective Science Communication (EEES)  
framework (adapted from Wack et al., 2021). Elements are organized into interrelated strategic  
categories of who, why, what, and how. The element of purpose is broken down into important  
SciComm objectives as defined by Besley et al. (2018).

**846**  
**847 Figure 2.** Example product from student Zoe. This product was coded to include the following  
elements with the types and levels indicated in parentheses: audience (general, primarily young  
adult to adult), content (apex predators and ecological topic; human and biological components),  
dialogue (social media Q&A and conversations with audience members; high), language (no  
jargon, mixed formality), mode (remote location; print media), platform (social media, specifically  
Twitter), and engagement (asks specific questions; low). The product was absent of style, appeal,  
and context. The elements of prior knowledge, purpose, and theory were not observable for any  
products.



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**855 Table Captions**

**856 Table 1.** Demographic information from the students and their coursework (plans and products)  
**857** included in this research. Numbers represent students in each category of consenting students and  
**858** the student plans and products that were available for this research.

**859 Table 2.** Presence of Essential Elements for Effective SciComm in student projects out of 27 plans  
**860** and 21 products. Elements that were not observable are denoted with NA. Brackets in the left  
**861** margin indicate which elements were explicitly addressed in the assignment instructions and  
**862** rubric.

**863 Table 3.** Thematic categories and subcategories of students' target audiences out of 27 plans and  
**864** 21 products. Numbers represent the number of students that defined their audience with each  
**865** category (i.e., specificity, age, or interest) and subcategory. Percentages represent the percent of  
**866** students that described their audience with the subcategory (e.g., adult) out of the number of  
**867** students that defined their audience within the broader category (e.g., age).

**868 Table 4.** Science communication objectives students reported as the purpose of their projects out  
**869** of 27 plans analyzed through the work by Besley et al., (2018). \*Not present in the Besley  
**870** framework but emerged from our data. Objectives were not observable in products.

**871 Table 5.** Thematic categories and subcategories of content out of 27 plans and 21 products.  
**872** Numbers represent the number of students that included a biological or human component or  
**873** focused on the listed topics.

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**874 Table 6.** Thematic categories of how students communicated, including dialogue, engagement,  
**875** language, mode, and platform out of 27 plans and 21 products. Numbers represent the number of  
**876** students under each subcategory.

# The Essential Elements for Effective Science Communication

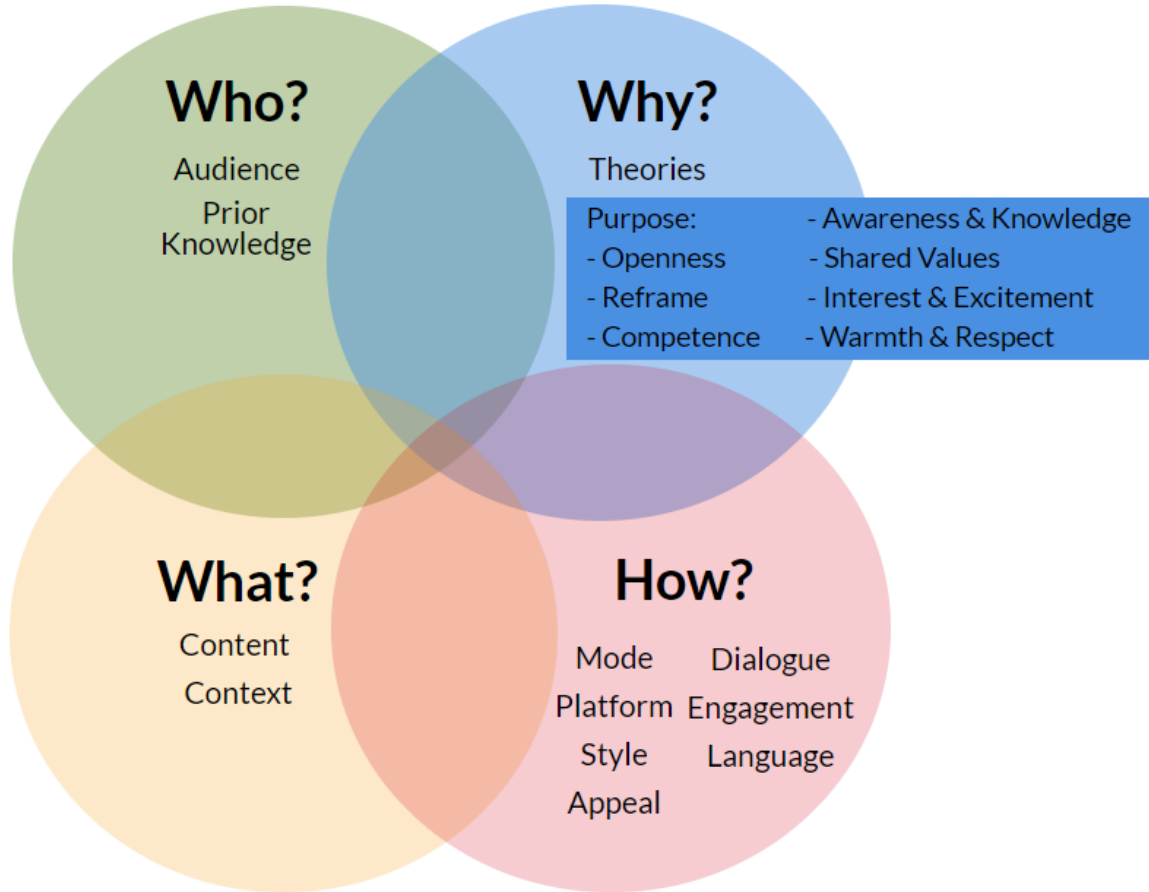






Figure 2.


 **Tweet** 

 Zoe 

Trophy hunting is a controversial topic that is currently in the news. Is there such a thing as sustainable trophy hunting?



Yes	29%
No	71%

7 votes · 8 hours 20 minutes left  
11/27/17, 9:46 AM





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 Zoe  10h





This is a tough one! I don't feel that either answer is particularly correct. However, because trophy hunting is essential for the economies of many African countries, it provides incentive to keep populations up of lions & other species [#predtrivia](#)

  1  



---

 Zoe  10h





However, when unregulated it is very bad for species! It is important to balance the needs of the humans in the area with the needs of the environment - although they usually go hand in hand [#predtrivia](#)



---

 Zoe  10h





Providing training and resources to promote "sustainable trophy hunting" could make a difference! [#predtrivia](#)

  1  



---

 Alex 





just read an article about this the other day, i had no clue it could be good. i still dont like thinking about lions being killed!

 1   

---

 Zoe  4h

It's an interesting topic, isn't it? It's hard too because when talking about these topics it's also important to think about the people who live there. Should we be putting \$ into helping them meet basic needs rather than lions? Thanks for your comment! [#predtrivia](#)

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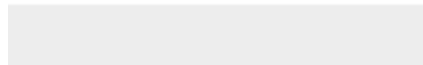


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