2015

Formation and Assessment of a Tool to Evaluate STEM Literacy in Service-Learning Projects

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Hayford, B., Blomstrom, S., & Mumpower, L. (2015). Formation and assessment of a tool to evaluate STEM literacy in service-learning projects. Journal on Excellence in College Teaching, 26(4), 73-101. Link to Journal: http://celt.miamioh.edu/ject/

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The purpose of the authors' research was to create a tool to evaluate science, technology, engineering, and mathematics (STEM) literacy in service-learning projects. The researchers posited that components of service-learning, which in this case included the deliverable and reflections, are examples of fundamental STEM literacy and thus can be assessed for STEM learning outcomes. The authors review the literature on service-learning and on STEM literacy. Combining components of literacy-based learning objectives and service-learning objectives with the revised Bloom's taxonomy in a taxonomy table, they created a general STEM literacy evaluation tool. They then applied the tool to a service-learning project as a case study. The results indicate that the tool effectively evaluated students' STEM literacy in a service-learning project and that it can be used to determine which literacy components, such as individual knowledge categories and learning objectives, were predictive of successful STEM literacy.

Introduction

Pedagogical Background for Service-Learning

Service-learning is an inherently project-based pedagogy that has been shown to impact learning outcomes (Perry & Imperial, 2001). Combining authentic learning experiences in a real-world environment with critical reflection, service learning improves students' complexity of thought (Eyler & Giles, 1999). Astin, Vogelgesang, Ikeda, and Yee (2000) analyzed a large longitudinal data set (over 22,000 students over a four-year period) and found that service-learning led to improvements in academic performance. Furthermore, service-learning has been linked to improvements in learning outcomes in community colleges, with students scoring significantly higher on institutional student learning outcomes, including communication and career/teamwork skills (Prentice & Robinson, 2010). Felten and Clayton (2011) showed that service-learning serves as ". . . a high-impact pedagogy across institution types and levels" (p. 76) because it may ". . . include critical reflection and assessment processes that are intentionally designed and facilitated to produce and document meaningful learning" (p. 76).

In particular, service-learning has been a successful pedagogy in science, technology, engineering, and mathematics (STEM) courses (Ghosh-Dastidar & Tsenova, 2012; Gormally, Brickman, & Lutz, 2012; Hamann & Drossman, 2006; Tedesco & Salazar, 2006). Assessment of learning outcomes is problematic, however, and few studies on service-learning, particularly in STEM courses, involve rigorous research techniques (see Hayford, Blomstrom, & DeBoer, 2014). Felten and Clayton (2011) indicate that a literacy component (for example, analytical essays) may be informative in capturing learning outcomes related to service-learning. In addition, Yorio and Ye (2012) found that a literacy component may be an informative indicator of cognitive development in learning outcomes related to service-learning. Thus, assessing literacy shows potential as a tool for evaluating the efficacy of service-learning pedagogy, particularly in STEM courses.

Review of Science Literacy Theory

Improving STEM literacy is increasingly becoming a focal point of STEM education (Krajcik & Sutherland, 2010; Reynolds, Thaiss, Katkin, & Thompson, 2012) and has been linked explicitly to service-learning projects (Reynolds & Ahern-Dodson, 2010; Reynolds & Lowman, 2013). Much of the research reviewed herein relates more specifically to science literacy, which is considered to be an integral component of science education. Definitions of science literacy have varied over the decades (Laugksch, 2000), but recently they have been distilled into two unifying categories typically associated with applied and basic literacy (Pearson, Moje, & Greenleaf, 2010). Norris and Phillips (2003) split science literacy into *fundamental* and *derived* senses. They defined fundamental science literacy as reading and writing science. They defined derived science literacy as the state of being "knowledgeable, learned, and educated in science" (p. 224).

Yore and Treagust (2006) adopted and expanded on Norris and Phillips's (2003) definition of STEM literacy as follows:

> 1. [Fundamental STEM literacy:] A literacy component that stresses the cognitive abilities, critical thinking, habits of mind and the information communication technologies (ICT) to understand the big ideas in science; to inform and persuade others about these ideas; and to participate more fully in the public debate about [STEM] issues. (p. 293)
>
> 2. [Derived STEM literacy:] The meaningful understanding of knowledge about the big ideas or unifying concepts/themes of science like the nature of science, scientific inquiry, and major conceptual themes in the biological, earth, and physical sciences.

Note that both the derived and fundamental senses of science literacy described by Yore and Treagast (2006) involve cognitive categories within Bloom's revised taxonomy (Krathwohl, 2002), and, hence, literacy components may be used to evaluate student learning outcomes in science courses. Yore and Treagust (2006) and Norris and Phillips (2003) emphasized that the two senses of science literacy are interdependent. Science is built by reading, contextualizing, critiquing, and understanding research that has already been done so that new research can be added and embedded within existing regimes or, most exciting of all, can expand or go beyond previous knowledge. Service-learning projects can be designed to include this interdependency of content and contextualization.

We agree with the arguments by Norris and Phillips (2003) and Yore and Treagust (2006) that the fundamental sense of science literacy is an often overlooked but necessary and important part of science learning and further suggest that both senses can be applied to STEM topics. Thus, though we recognize both the derived and fundamental senses of STEM literacy, we focused on the fundamental sense of literacy in designing this project. Transitioning from a home language, to a school language, to science language represents what Yore and Treagust (2006) call a *border crossing*. This border crossing may be considered in linguistic terms as a *register shift*, or the ability of a speaker to alter his or her speech in a given social situation (Reid, 1956). In the case of STEM learning, students must learn to shift from their home language or common vernacular to a school language, or STEM jargon.

Border crossing is one of five important themes in Kiely's (2005) model of transformative learning in service-learning, and it pertains directly to a fundamental sense of STEM literacy as it involves reading, writing, language acquisition, and reflection. We modify Kiely's themes to fit transformational learning through STEM literacy in service-learning as follows: *Border crossings and dissonance* occur when students transition from their common vernacular to STEM jargon and then back to the common vernacular, with the dissonance resulting from the incongruence between participants' prior knowledge and new knowledge; *personalization* is characterized as an individual student's response to the different types of dissonance; *processing* is characterized as both an individual reflective learning and a literary dialogic learning process in which a student responds and communicates using STEM discourse; and *connecting* is the act of learning to understand and empathize through relationships with community members, peers, and faculty. Service-learning projects that include or are focused on written and oral science communication can be used to enhance STEM literacy and, by doing so, create an inherently transformational learning experience for students. Each of these themes can have a fundamental literacy component and, so, can be used to evaluate STEM literacy in service-learning projects.

Service-learning is a powerful pedagogy, and projects can be designed to focus on literacy and to emphasize the inherent literacy components such as reflection. Based on a review of the literature, we combined elements of literacy-based learning objectives and service-learning objectives with the revised Bloom's taxonomy to create a STEM literacy evaluation tool. We applied this tool as a case study to answer the following research questions.

> R_1: How can we measure STEM literacy in a service-learning project?
>
> R_2: What is the efficacy of the STEM literacy measure?

Methods

Project Description and the STEM Service-Learning Literacy Tool

We first developed a general STEM service-learning literacy (STEMSL) tool that incorporates the transformational components of service-learning listed above with principles of fundamental STEM literacy and the basic tenets of Bloom's revised taxonomy (Krathwohl, 2002) (see Apapendix A). We created a taxonomy table and incorporates our modified transformational service-learning themes from Kiely (2005). Second, we modified the general STEMSL tool for use in evaluating STEM literacy in a service-learning project. However, before we produce the modified tool, we should describe the service-learning project.

Project Description

The service-learning project is based on a model of college students communicating STEM information to a target audience of K-12 students. The college students learn STEM concepts and language or jargon through research, then translate the information into a common vernacular for the target audience. The model is based on a multi-aged approach in which college students create audio files for younger students. Specifically, students from Embry-Riddle Aeronautical University (ERAU) created digital audio files providing content on an assigned specimen displayed in a natural history museum in a rural area for regional K-12 students and casual visitors to the museum. Museum visitors can access the audio files made available via the museum's online site using smart devices, or people may access the audio files online from their computers or smart devices. ERAU students were instructed to develop and deliver audio presentations on specimens or STEM topics they were unfamiliar with, requiring them to conduct research. Students were asked to write what they knew about the specimens or topics they were assigned. They were given specific instructions and feedback from the director of the museum. They received feedback on their drafts and later on their final products. During the Spring 2014 Semester, students received individual written feedback on the written drafts of their presentations. During the Fall 2014 and Spring 2015 Semesters, students received individual, face-to-face feedback on their presentation rehearsals. This feedback on rehearsals was given in the classroom setting so students could hear the feedback given to other students. The students' knowledge was enhanced through the formative feedback, and the final written and oral deliverables could be evaluated as forms of STEM literacy.

Embry-Riddle Aeronautical University. Embry-Riddle Aeronautical University (ERAU) is "the world's oldest and largest fully accredited university specializing in aviation and aerospace" (ERAU, 2015).offering degrees in aerospace and other types of engineering, aviation science and aviation-related degrees, meteorology, safety, security and intelligence, space physics, and business. The university has two residential campuses and a worldwide campus that offers online programs. ERAU offers bachelors, masters, and doctorate degrees. This project took place at the Daytona Beach, Florida campus.

A. Jewell Schock Natural History Museum. The community partner for this project was the A. Jewell Schock Museum of Natural History, housed at Wayne State College in Wayne, Nebraska, which boasts nearly a 40-year history. The museum's mission is to ". . . preserve natural diversity of life in Northeast Nebraska through maintaining and adding to our collections, through science education and outreach, and through actions to conserve and restore natural habitat in the region" (WSC Museum, 2015). Because the museum is located in a small town and rural landscape, staff wanted to extend their reach through the production of digital audio files. They also wanted to enhance the museum experience for visitors by linking audio files to specimens on display.

Project Details

A total of 240 students enrolled in a required course, COM 219: Speech, at ERAU during the study. Students were given a service-learning assignment to create digital audio files about individual specimens in the Natural History Museum's collection. Students were instructed to provide general information on the biomechanics of movement for walking, flying, and swimming specimens during the spring semester of 2014 and were instructed to provide more detailed information on the biomechanics of flight for birds during the fall semester of 2014, information on the biomechanics of insect flight, bird flight, and on nanotechnology for the spring semester of 2015. The project was designed to include all four elements of STEM learning: *science* of biomechanics and basic biology of the specimens and nanotechnology; *technology,* involved in creating the digital audio tours; *engineering* and technology, by applying biomechanics and nanotechnology to robotics and/or aeronautic engineering; and *mathematics*, involving ratios and, in some cases, equations related to biomechanics and nanotechnology (that is, Bernoulli's equation). Twenty-one students did not complete the project.

Students represented all four of ERAU's colleges and ranged from first-year students to seniors. Learning objectives for the project were linked directly to the categories and action verbs of the revised Bloom's taxonomy (Krathwohl, 2002). The following definitions are taken from Krathwohl's (2002) structure of the cognitive process dimension of the revised taxonomy and are followed by how these definitions were applied to the student learning objectives (SLOs) for the service-learning project.

> ***Understand***: determining the meaning of instructional messages, including oral, written, and graphic communication. *SLO:* Students will determine the meaning of source STEM materials and effectively communicate this through comparing, classifying, explaining, and summarizing the information.
>
> ***Apply***: carrying out or using a procedure in a given situation. *SLO:* Students will apply STEM knowledge by following the assigned procedure to execute a communication product effectively for the community partner.
>
> ***Analyze***: breaking material into its constituent parts and detecting how the parts relate to one another and to an overall structure or purpose. *SLO:* Students will break down STEM material into constituent parts and then relate how the parts relate to one another and different materials.
>
> ***Evaluate***: making judgments based on criteria and standards. *SLO:* Students will select, use, and cite appropriate source materials and will check and critique their work with the community partner.
>
> ***Create***: putting elements together to form a novel, coherent whole or make an original product. *SLO:* Students will create a new communication for the community partner based on the STEM materials.

We did not include the first category in the revised Bloom's taxonomy, *Remember*, because the written and oral components of STEM literacy seldom require clear demonstrations of the actions related to remembering.

The project was designed to meet the service-learning objectives modified from Hayford et al. (2014) and Billig and Weah (2008):

1. Links to curriculum: The literacy assessment showed connections between communication learning outcomes and the service-learning project;

2. Partnership and meaningful service: Students and the community partner participated in a reciprocal relationship;

3. Reflections used as a form of literacy: This also involved self-awareness (metacognition); and

4. Duration and intensity: The project lasted 4-6 weeks and was a major assignment of the class.

Four script guidelines were given to the students over the spring semester 2014, fall semester 2014, and spring semester 2015. Each script was designed to enhance students' STEM literacy and followed a similar format (see Figure 1), with the exception of the script for spring semester 2014.

Prompts for eliciting students' reflections were modified from prompts successfully used in previous service-learning courses over the past five years. These prompts were modified by directly applying components of projects to many of the questions. Students were required to provide written responses to those reflective prompts. We included components from those reflections related to students' service-learning experiences (see Figure 2). Students were given several weeks to complete their reflections on-line. Reflection links service to learning (Eyler, 2002) and, thus, is an important tool in evaluating the success of the service-learning projects. We have found that reflection prompts related directly to specific learning objectives in service-learning projects are useful in determining the efficacy of service-learning pedagogy (Blomstrom & Tam, 2009; Hayford et al., 2014).

The STEM Service-Learning Literacy Tool

The STEM Service-Learning Literacy (STEMSL) tool was based on the literacy and service-learning components linked explicitly to Bloom's revised taxonomy through the STEM learning objectives, service-learning objectives, and knowledge content for the project (see Tables 1 and 2).

Analytical Methods

Students' STEM literacy was evaluated using three tools: (1) a student skill self-survey, (2) a two-part STEMSL tool that evaluated audio tours and analyzed metacognitive reflections by students, and (3) the selection of students' audio tours by the museum director.

First, at the beginning and again at the end of each semester, students responded to a student skill survey in which they self-reported their

Figure 1
Rough Draft Format Biomechanics of Flight, Fall 2015

1. General Museum information (optional)
2. General information on biomechanics
3. Give the common name and genus and species names for the specimen and then use only the common name after that.
4. Tell the listener what type of bird your specimen is (choose from: shore bird, water fowl, ground bird, song bird, bird of prey).
5. What is its general habitat and method of feeding (is it a predator, seed eater, insect eater)?
6. Note that the species is found in North America and can often be seen in Nebraska.
7. General information biomechanics of flight from (http://www.ucmp.berkeley.edu/vertebrates/flight/physics.html)
8. Describe the size and shape of the bird and how that relates to the bird's flight.
9. Describe the shape of the wings and how this shape may relate to flight.
10. Does the bird have to run to fly? Does it take off from the water? Does it drop from a tree?
11. How does the bird land using its wings and tail feathers?
12. How does the bird fly? Your description should make use of concepts such as airfoils, lift, supination and pronation, wing rotation.
13. Compare flight to one other type of bird.
14. Application of those biomechanics in robotics or aeronautics.
15. Create a bibliography for your final script.

skills in areas related to STEM literacy. We recognize the limitation of self-reported data, yet this type of data can be effective in assessing service-learning outcomes (Blomstrom & Tam, 2009). The student skill survey was primarily developed based on the competencies in communication and collaboration skills described by Morreale, Rubin, and Jones (1998), which was available from the National Communication Association (NCA) website. The skills identified in that article formed

Figure 2
Prompts for Reflection Fall 2014

Please write out responses to these questions and submit them through Blackboard. This assignment is to be completed within one week of your audio presentation.

1. What was your topic?
2. What did you do for the project? Please specifically include the research you did for the project and discuss how the research you did may be similar to research you will do in the future.
3. List your main points and write out what you now know about each of the points. How did you gain information about your topic? What did you learn about your topic through this project? Did presenting on the topic cause you to get to know the subject matter better?
4. Three (3) characteristics of effective informative speaking have been identified: a speech should be intellectually stimulating, relevant to the audience, and creative. How did you incorporate these three (3) characteristics in your presentation?
5. Identify 2 discoveries you made. What did you learn about yourself? Did you employ a new creative skill, do you see yourself as more confident? Did you become aware of assumptions you held—perhaps about the audience? Did you learn something new about delivering a presentation using technology?
6. How did you analyze your audience? How did your analysis affect your planning for your presentation? How can you apply what you learned about adapting to the audience in your future career communication?
7. In five lines of text describe what you would do differently. For example, would you prepare introductory remarks differently?
8. How did the experience better help you understand what you are learning in the course? Please address audience analysis, content development, organizing your speech, delivery, and incorporating feedback.
9. Please describe how you can use what you learned from this experience in your career communication.
10. Did you come across the way you wanted to? What elements do you want to work on in the future?
11. This speech assignment has the elements of students addressing a real-world issue (STEM knowledge and interest for K-8 students visiting the museum), receiving feedback from the museum director, and delivering a presentation using technology. Was this assignment effective for you? Why or why not? Was the feedback you received helpful?

Table 1
Modified STEMSL Tool for the ERAU Service-Learning Project Without Reflections

	Understand	*Apply*	*Analyze*	*Evaluate*	*Create*
Factual Knowledge	Identify and list basic biology, ecology information.		Break down and describe biomechanics and how birds fly.		
Score 0-4					
Conceptual Knowledge	Classify specimens and habitat types.		Relate biomechanics to bird wing shape and landing dynamics.	Use informative and relevant sources.	
Score 0-4					
Procedural Knowledge	Compare to other species.	Carry out the procedure of writing script according to guidelines.	Relate biomechanics of flight to robotics and planes.	Incorporate feedback in preparing final version of text.	Create MP3 file.
Score 0-4		S/NS*			

Note. *Indicates whether this category was successfully met and that the scoring did not fit into the 0-4 scoring based on the preliminary analysis.

Table 2
Modified STEMSL Tool for the ERAU Service-Learning Project Reflections Including Prompts Used in Analysis for Metacognitive Knowledge

Understand	*Apply*	*Analyze*	*Evaluate*	*Create*
What did you do for the project? Please specifically include the research you did for the project.	How did you analyze your audience? How can you apply what you learned about adapting to the audience in your future career communication?	Identify two discoveries you made.	In five lines of text, describe what you would do differently.	How did the experience better help you understand what you are learning in the course?

the basis of NCA's expectations for students who have taken one college speech course. The items primarily represent the educators' perspective. Items were selected from the extensive list of competencies given based on how well they fit with the speech course taught at our institution. We supplemented the selected skills from Morreale et al. (1998) with skills identified by practitioners. Those skills were selected from the Commission on Public Relations Education 2006 report (Turk, 2006). The resulting instrument includes 57-items grouped under five factors.

Second, the STEMSL literacy tool provided two opportunities for evaluation and analysis. The upper half of the taxonomy table was used to evaluate literacy expressed by the student's audio tours (see Table 1). The items in Table 1 were scored as follows: 0 (*does not do activity*), 1 (*does activity but does not meet learning objective*), 2 (*meets learning objective*), 3 (*excels at leaning objective*), and 4 (*exceeds learning objective*).

The lower half of the STEMSL literacy tool was used to assess the metacognitive aspects of learning based on reflections. Table 2 presents the reflective prompts used for analysis to evaluate the knowledge dimension of metacognitive knowledge for each of the cognitive process dimensions. Students' reflective responses to the prompts were rated using a 1-4 scale, as follows: 1 (*the student did not meet the learning objective*), 2 (*the student met the learning objective*), 3 (*the student excelled*), and 4 (*the student exceeded the learning objective*). The scoring process requires further elaboration, particularly for scores of 3 and 4. A score of 3 indicated that students were thought to excel at a learning objective if they included the STEM jargon and gave a definition or explanation in the common vernacular. A score of 4 indicated that students were thought to exceed the learning objective by including analogies or added materials, such as bird calls or stories, for example.

Third, the virtual audio tours created by the students were selected by the museum director for use in the museum based on the degree to which the tours addressed content required by the instructions and illustrated by the script. The instructions in Figure 1 are scripted (see Figure 1). Other criteria used for selecting the tours included the clarity and quality of the student tour guide's speech, the enthusiasm of the student, and the student's use of examples and explanations of STEM content for the target audience. Thirty students from fall semester 2014 were randomly selected using a random number generator, and their audio tours were evaluated using the STEMSL literacy tool. The 5-point scoring scale for the "Apply" learning objective in Table 1 was changed to a *successful/not successful* score that could not be included in the analyses detailed below. Nearly all of the tours submitted by students for spring semester 2015 were added to the

30 tours used in the preliminary analysis for the remainder of the study.

Drawing from Pintrich's (2002) work, within metacognitive knowledge, strategic knowledge includes general strategies for learning that are applicable across different tasks in different domains. People can have knowledge about cognitive tasks, and they can also have self-knowledge. Because we were looking for evidence of student's knowledge about learning, we looked at student reflections, rather than transcripts of the students' audio tours, to investigate evidence of metacognitive knowledge. This analysis included a random selection of 31 reflective papers from the fall semester 2014 and 31 reflective papers from the spring semester 2015 (see Figure 2).

To evaluate students' metacognitive knowledge about the element "Understand," we asked them to demonstrate their knowledge of and ability to do research. To earn a minimum acceptable score of "2," students needed to write about how they conducted research for the project. To demonstrate their ability to "Apply," students needed to identify how they used audience analysis in writing their presentations, which demonstrated their awareness of implementing the concept of audience analysis in a practical way, and to address how the experience could be applied to their career communication. To demonstrate their ability to "Analyze," students needed to show self-awareness of what they discovered through the experience. To measure students' ability to "Evaluate," we analyzed their responses to two reflection prompts: a prompt asking what they would do differently what they would do differently to complete the assignment and a prompt asking them whether the feedback they received was helpful. Responses to both prompts indicated students' ability to apply criteria and standards. To evaluate students' ability to "Create," we examined students' responses to a prompt asking how the service-learning experience helped them understand the content of the course.

Ultimately, students' achievement of STEM literacy in this service-learning project was determined by the selection of their digital audio tour by the museum director community partner. Most students were successful with the individual components of STEM literacy as evaluated by the STEMSL, but complete success involved their communicating the STEM topics to the lay audience of the museum through their virtual tour, particularly because this task involved register shifts and border crossings for the students. We used the selection of students' tours as a way to corroborate the efficacy of the STEMSL tool. Summed scores for the learning objective and knowledge categories on the STEMSL tool taxonomy table were calculated for each student. Then a one-way analysis of variance (ANOVA) was run to examine whether scores for each STEMSL tool varied significantly between those tours chosen for the museum versus those not chosen. Discriminant analysis was run using stepwise backward selection of variables (with selection criteria set at a p value of .10) to determine which literacy aspects of the project, as represented by the STEMSL tool categories, were the strongest predictors of whether a digital audio tour was selected for use in the museum. Significance for the ANOVA and discriminant analyses was set at $p < 0.05$ and was performed using Number Cruncher Statistical Software.

Results

A total of 16 student digital audio tours were selected for use in the museum for spring semester 2014, compared to 35 selected for use by the museum during fall 2014, and 34 selected for use during spring 2015. These numbers indicate successful STEM literacy for many of the student participants, but not for all. Results from the student skills survey show that students perceived they had improved their STEM literacy related to the project in general (see Table 3). *The student skill survey consisted of 57 items. In our analysis we included responses only to those items that directly related to the students' awareness of the audience and of selecting materials and language appropriate for the target audience, also their skill related to creating the digital audio tour.* Survey responses indicated that improvement ranged from 15-25% in spring semester 2014, from 11-24% in fall semester 2015, and from 15-23% in spring semester 2015, with a mean improvement of 19% for all three semesters (see Table 3).

The project evolved over the three semesters. Students in all three semesters participated in service-learning and created an audio tour; thus, we were able to compare their self-reported skills between the three semesters (see Table 3). However, the spring semester 2014 project did not include face-to-face feedback from the community partner and involved major differences in the script instructions. Because the project conducted during fall 2014 and spring 2015 semesters more closely reflects our vision for the project, we will focus on the data from these semesters for the remainder of this article.

Two knowledge categories and one learning objective from the STEMSL tool based on the audio tours were identified by the discriminant analysis model as predictors of whether a student's tour was selected or not. "Conceptual knowledge" and "procedural knowledge" were both significant predictors of selection ($p < 0.001$ for both categories). The "create" learning objective was not a statistically significant predictor of tour selection.

Tour scores using the STEMSL were all significantly higher for tours se-

Table 3
Percentage Differences in Students' Self-Reported Skills From the Beginning of the Semester to the End of the Semester

Skills Survey Items	*Spring 2014 Increase*	*Fall 2014 Increase*	*Spring 2015 Increase*
Adapt and narrow topic to the context in terms of audience and setting.	22%	19%	19%
Locate, evaluate, and use information resources.	16%	17%	17%
Based on your research, select appropriate support materials based on the topic, audience, setting, and purpose.	17%	18%	20%
Select language appropriate to the topic, audience, purpose, context, and speaker.	17%	11%	15%
Choose words to clearly express ideas, to create and maintain interest, and to enhance your credibility.	18%	16%	17%
Use creativity in writing the speech.	15%	19%	19%
Adapt speech to audience.	24%	24%	21%
Use vocal variety to heighten and maintain interest.	16%	24%	18%
Articulate clearly.	16%	19%	18%
Speak confidently.	18%	21%	20%
Speak dynamically.	22%	22%	23%
Use creativity in the delivery of the speech.	25%	22%	22%

lected than for those not selected, with the greatest difference evident in the "procedural" category (see Table 4). Reflection scores using the STEMSL were higher in all knowledge categories and learning objectives for tours that were selected for use by the museum director versus those that were not selected (see Table 5). Although none of the scores was significantly higher for tours that were selected, scores for "Evaluate" and cognitive thinking were both close to being significant ($p = 0.09$; see Table 5).

Table 4
Results From ANOVAs Comparing STEMSL Learning Objectives and Knowledge Categories Based on the Tour Scores Between Digital Tours That Were Selected Versus Those That Were Not Selected

Learning Objective and Knowledge Category (Significance)	*Selection*	*Mean (Range)*	*Standard Deviation*	*Standard Error*
Factual Knowledge ($p < 0.001$)	Not Selected	4.98 (2-7)	1.36	0.17
	Selected	5.89 (4-7.5)	0.90	0.13
Conceptual Knowledge ($p < 0.001$)	Not Selected	7.06 (2-10)	1.77	0.22
	Selected	8.60 (6-10.5)	1.12	0.16
Procedural Knowledge ($p < 0.001$)	Not Selected	6.10 (2-12)	2.51	0.31
	Selected	9.72 (5-13.5)	2.01	0.30
Understand ($p < 0.001$)	Not Selected	6.25 (1-9.5)	1.76	0.21
	Selected	7.74 (3-10)	1.40	0.21

Table 4 (*continued*)
Results From ANOVAs Comparing STEMSL Learning Objectives and Knowledge Categories Based on the Tour Scores Between Digital Tours That Were Selected Versus Those That Were Not Selected

Learning Objective and Knowledge Category (Significance)	*Selection*	*Mean (Range)*	*Standard Deviation*	*Standard Error*
Analyze ($p < 0.001$)	Not Selected	6.40 (0-10.5)	2.54	0.31
	Selected	8.47 (3-10.5)	1.59	0.23
Evaluate ($p < 0.001$)	Not Selected	3.34 (0-6)	1.43	0.17
	Selected	4.73 (0-6.5)	1.20	0.18
Create ($p < 0.001$)	Not Selected	2.20 (0-4)	0.93	0.11
	Selected	2.88 (0-4)	0.75	0.11

Note. Total $n = 113$; Selected $n = 46$; Not Selected $n = 67$.

Table 5
Results From an ANOVA Comparing STEMSL Learning Objectives and Knowledge Categories Based on Reflections Between Digital Tours That Were Selected Versus Those That Were Not Selected

Learning Objective and Knowledge Category (Significance)	*Selection*	*Mean (Range)*	*Standard Deviation*	*Standard Error*
Cognitive Thinking ($p = 0.09$)	Not selected	11.74 (7-16.5)	1.78	0.29
	Selected	12.58 (9-16)	1.92	0.38
Understand ($p = 0.76$)	Not selected	2.24 (1.5-4)	0.48	0.08
	Selected	2.28 (1.5-3)	0.46	0.09
Analyze ($p = 0.33$)	Not selected	2.38 (1-4)	0.67	0.11
	Selected	2.54 (1.5-4)	0.58	0.12
Apply ($p = 0.14$)	Not selected	2.24 (1-3)	0.52	0.08
	Selected	2.46 (1.5-4)	0.64	0.12
Evaluate ($p = 0.09$)	Not selected	2.54 (1-4)	0.72	0.12
	Selected	2.84 (2-4)	0.61	0.12
Create ($p = 0.47$)	Not selected	2.34 (1-4)	0.67	0.11
	Selected	2.46 (1-4)	0.63	0.13

Note. Total $n = 62$; Not Selected $n = 37$; Selected $n = 25$.

Only "cognitive thinking," a component of the knowledge category in the reflection part of the STEMSL tool, was a predictor of whether a tour was selected or not. However, it was not a statistically significant predictor (Table 5).

Responses to the reflection prompts showed some variation. Some students, such as the one in the following example in response to the question asking students to write about two discoveries they made, wrote specific, detailed responses indicating their learning and their awareness of how that learning applied to the larger context:

> I discovered a boost in my confidence and an increase in my knowledge of flight. I learned more about how birds fly from a technical standpoint, and I found that as a big plus towards my aviation education. I learned more about using technology for delivering my presentation because it helped make my presentation more attractive and appealing with in-depth information to better gain the audience's interest about the subject.

Other students wrote simpler, shorter answers, which may or may not indicate less learning. More detailed answers in some cases clearly indicated more in-depth knowledge, such as this response to question 6 about audience analysis:

> Knowing that this was a piece for a museum, I searched the Internet for articles discussing museum visitors' profiles. I found a website called "Museum Audience Insight" (http://reachadvisors.typepad.com/museum_audience_insight/2010/04/whos-coming-to-your-museum-demographics-by-museum-type.html). The web page claimed science-museum visitors are mostly under age 50, are likely to be college educated and [to be] accompanied by elementary school-age children. Several other websites concurred. To appeal to this audience I went for a lively presentation, with some slow, slightly technical parts. I included some information that elementary-school-goers might not be privy to, with the assumption that they would ask the adults accompanying them.

Register shifting exhibited by border crossing has previously been described as the ability of a speaker to alter his or her speech depending on social situations (Reid, 1956). When speakers change their vocabulary choices and style when speaking to their family, they are effectively crossing a border between informal and familial speech. While register shifts are often discussed in terms of speech, we can relate this notion to writing, particularly a student's efforts at STEM writing for a lay audience. STEM writers must also make these register shifts as they read, evaluate, and process scientific and technical content that then has to be translated by these same writers to a lay audience. As we can see from the examples below, these register shifts were not always successful.

> **Example A:** Fully extended wings are used while gliding. On the other hand, during high-speed flights, wings are often bent and wingtips are swept back. The wing surface area highly depends on the dihedral angle.

The previous example was evaluated as a less-successful attempt at register shifting, primarily because of the reference to a "dihedral" angle of the wing. While the student is technically correct, the assignment asks students to write to a lay audience, one that would require a register shift from technical to informal prose.

> **Example B:** The American Kestrel's shape and size roughly matches with the mourning dove. Longer narrow wings, long squared-tip tail, rounded head with colorful body. It weighs about 100 grams, a little less than 4 ounces.

This example, from the same student writer, shows how the student finds more commonly known examples to which to relate the "shape and size" of the American Kestrel. By using the example of the more familiar mourning dove, the student adapts scientific content for the particular social situation of a casual museumgoer with little to no prior knowledge of the subject. By offering two descriptions of the Kestrel's weight (both in grams and ounces), the writer shows an ability to cross the linguistic border between the scientific content provided by the museum's director and adapt it to the museum's visitors.

Discussion

We have developed a general STEMSL tool (see Appendix A) and have shown how the tool may be modified for use in this case study. The tool was effective in evaluating students' STEM literacy in a service-learning project. Because the STEMSL tool is based on a matrix using elements of Bloom's revised taxonomy as learning objectives and structural elements of knowledge (Krathwohl, 2002), its use allowed us to examine which learning objectives and knowledge categories best predicted effective STEM literacy by the students. The significant increase in students' achievement of learning objectives based on the STEMSL scoring corroborates research showing that service-learning positively impacts learning (Astin et al., 2000; Warren, 2012) and shows that the tool holds promise for use in evaluating STEM literacy as a course outcome.

Conceptual, procedural, and cognitive knowledge were all identified as predictors of successful STEM literacy, but factual knowledge was not. Our results come as no surprise, because service-learning pedagogy typically involves higher-level learning, such as cognition (Yorio & Ye, 2012), and the acts of reading and interpreting and then communicating STEM topics are cognitive processes (Yore & Treagust, 2006). Felten and Clayton (2011) have suggested that "factual knowledge and lower-level learning goals might not adequately capture service-learning's most significant contributions to students' academic development. . . . [O]n higher order thinking tasks, such as analytical essays and case-based assignments, students in service-learning sections consistently performed better than their peers" (pp. 79-80). These researchers indicate that a course literacy component (such as analytical essays) may be informative in capturing the achievement of learning outcomes related to service-learning (Felten & Clayton, 2011).

Our work supports research similar to Ash and Clayton's (2009) showing that student reflections can be used to evaluate service-learning projects effectively. The STEMSL tool was useful in identifying an increase in learning objectives for the reflections, as well, supporting other research (Blomstrom & Tam, 2009; Hayford et al., 2014). The reflections were informative in other ways, with students providing examples of what they had learned, giving specific details using translational language. Reflections in STEM literacy projects combined with explicit course requirements involving reading, writing, and oral communication exhibit great potential to enhance literacy in STEM courses.

Limitations and Suggestions for Future Research

Students' effective STEM literacy was ultimately measured by the selection of students' digital audio tours by the community partner. This limits the applicability of this study as a model for future studies. The community partner was the director of the museum and, therefore, was STEM-literate and able to evaluate STEM content directly. Not all community partners will be able to perform this function. We suggest that for service-learning projects designed or modified using this model students include a rough draft featuring the use of STEM jargon for comparison to the final communication delivered using the common vernacular. We designed our project to include—and to some degree integrate—science, technology, engineering, and math. The STEMSL tool may be used to evaluate the use of math, but we did not adequately measure math in the project. We suggest including an explicit instruction in future assignments directing students to make some sort of mathematical comparison or to apply STEM content using mathematical analysis.

The reflection component of this service-learning project was the most powerful part of the STEMSL tool, because it involved students demonstrating their fundamental literacy through writing and metacognition of self-awareness. Students reflected their self-awareness of what they learned in terms of content and of how to appropriately relate that content to the target audience. The *extent* of student's learning was not necessarily captured, however. Instructions for the reflective assignment were open to interpretation, and in order for this analysis to be more meaningful, the reflective assignment should be constructed differently. For example, we could make better use of elaboration in the tool to gather more information in assessing STEM literacy (see Appendix A). Brown, Roediger, and McDaniel (2014) define elaboration as "the process of giving new material meaning by expressing it in your own words and connecting it with what you already know" (p. 6). We asked students to elaborate on their learning by expressing in their own words connections to what they already knew prior to participation in the project. Reflection prompts may be designed to better elicit more consistent and comparable responses by the students.

Finally, this study was limited in samples size, so we suggest testing the STEMSL tool in a greater number of samples across different projects and STEM disciplines to determine its efficacy in evaluating STEM literacy and to refine the tool for greater applicability.

Implications

The general STEMSL tool (Appendix A) that we modified and applied to a case study may be modified for use in other service-learning projects. Furthermore, this tool may have application in evaluating STEM literacy outside of service-learning projects if those projects include reflections on learning. Because the project described here was part of a communications class, the focus was oral and written communications that we chose to focus on a STEM topic. Most STEM-content courses do not include reflections or other self-analysis tools of learning in communication or literacy-based projects. We suggest that the STEMSL tool has broader application to these courses if the literacy-based project is designed around the tool to better reflect literacy.

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Acknowledgment

The Center for Teaching and Learning Excellence at Embry-Riddle Aeronautical University (ERAU) - Daytona Beach campus for providing the Scholarship of Teaching and Learning grant for this project. ERAU's IGNITE program also provided funding for this inquiry-based project. Additional support came from the School of Natural and Social Sciences in funding the A. Jewell Schock Museum of Natural History at Wayne State College.

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Appendix A

General STEM Service-Learning Tool for Evaluating STEM Literacy (BC=Border Crossing/Dissonance; PR=Processing; CN=Connecting)

	Understand	*Apply*	*Analyze*	*Evaluate*	*Create*
Factual Knowledge	BC: Identify or list materials from readings suggests a shift from the vernacular to STEM-specific jargon.		BC: breakdown the materials from readings and relate the components to each other.		
Conceptual Knowledge	BC: classify read materials in a meaningful way that shows you understand the STEM jargon.		BC: relate the broken down materials to other like-materials so that new knowledge emerges.	PC: communicate the use of source materials by citing informative and relevant sources.	

Appendix A (*continued*)
General STEM Service-Learning Tool for Evaluating STEM Literacy
(BC=Border Crossing/Dissonance; PR=Processing; CN=Connecting)

	Understand	*Apply*	*Analyze*	*Evaluate*	*Create*
Procedural Knowledge	BC: compare materials from readings to other like-material.	PR: follow a specific process or format to communicate in written or oral form information based on STEM readings. Students apply what they know by following instructions in producing the written or oral literacy product.	BC: relate the broken down materials to different materials so that new knowledge emerges.	CN: judge the efficacy of the written communication in reciprocal relationship with community partner. Incorporate feedback from community partner/make changes based on feedback from community partner.	PC: create a written or oral communication based on STEM readings.

Metacognitive Knowledge	BC: Elaborate is to summarize readings and expand upon them with success determined via reflections.	PR: students reflect on the process they followed to obtain information indicating knowledge of research process.	BC: students analyze their learning related to the project, specifically whether completing the project caused (lead to) them getting to know the subject matter better	CN: show self-awareness through reflections based on evaluation of project outcomes, students are asked what they would have done differently now that they are done.	BC, CN: show self-awareness through reflection on whether the communication was successful in switching from STEM jargon back to the vernacular for the target audience. Specifically students reflect on whether they met audience expectations.