

Vol 9, No 2, December 2023

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Publisher / Founder : i-STEM / Gultekin Cakmakci ISSN:2149-8504



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RESEARCH REPORT

Sciencing Out, an informal STEM education program in Madagascar: A case-study

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Abstract: Sciencing Out (SciOut) facilitated by Explorer Home Madagascar Science Center, a Malagasy NGO, is an innovative STEM (Science, Technology, Engineering, and Math) education program because it incorporates out-of-school education, student and scientist collaborations, local and international partnerships, and arts education. This case-study describes the program's unique educational components alongside evaluation data to understand: How does a field program like SciOut help students engage with STEM topics? The results demonstrate that out-of-school, field-based experiences that connect students to local experts and biodiversity topics are important for increasing access to STEM knowledge and careers.

Keywords: STEM education; STEAM education; Madagascar; informal education; field-based experiences

Science, Technology, Engineering, and Mathematics (STEM) education is critical for empowering humankind to address big challenges such as climate change, pollution, and disease. STEM education is an important foundation for innovation especially when paired with creativity. If utilized responsibly and conscientiously, knowledge of STEM subjects can help us understand, adapt, restore, discover, and care for the abundant life around us. To accomplish this, increasing STEM access is paramount as the global challenges of the present and future require solutions that incorporate STEM knowledge (Marrero et al., 2014). As such, student interest and access to STEM is essential. To promote broader access amongst student populations, a variety of pedagogical approaches like the ones described below are needed in conjunction with in-school curriculum.

To cite this article: Dorsey, S., Andrianavalona, T., Ramihangihajason, N., & Brias-Guinart, A. (2023). Sciencing out, an informal STEM education program in Madagascar: A case-study. *Journal of Research in STEM Education*, 9(2), 46-77. https://doi.org/10.51355/jstem.2023.147

ISSN: 2149-8504 (online)

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To ignite student curiosity in STEM fields, *out-of-school learning* experiences are encouraged. This approach provides space for students to explore, fail, and create without the pressure of assessment (Bamberger & Tal, 2008; Stevens et al., 2016). In-school education builds knowledge over time, while out-of-school learning fosters prolonged interest in a subject through social interaction and experiences (Berry, 1998). In out-of-school settings, students are often encouraged to use inquiry to spark curiosity about the world around them. These experiential learning opportunities can lead to transformational encounters that spark deeper engagement with an academic subject (Houseal et al., 2014).

Another pedagogical approach is to encourage authentic learning experiences with field practitioners, which can provide students with a hands-on understanding of research processes, as well as access to the scientific community (Houseal et al. 2014). Allowing students to understand the intersections of different subjects through exposure to professionals through *student and scientist collaborations*, increases engagement. This can expand positive attitudes and interests in academic subjects, field professionals, and content knowledge (Houseal et al., 2014).

Cross-cultural exchange through *local and international partnerships* is an additional pedagogical approach that can foster respect for and wonder about the world, build relationships, and inspire continued learning among adults and students (Duraisingh, 2018). Opportunities to exchange ideas regionally and globally provides adults and students with the communication and critical thinking skills to collaborate across local territories and national borders, while solving the global challenges of the future and present (Mansilla & Jackson, 2013). These opportunities enable all involved to consider the viewpoints of others, while critically examining their own to learn the importance of multiple worldviews (Mansilla & Jackson, 2013). This approach builds a broader understanding of local and global narratives while developing respect for its complexity, and personal meaning to human communities around the world, including one's own (Duraisingh, 2018; Project Zero, 2016).

Arts education (drawing, painting, storytelling, videography, photography, music, poetry, etc.) is the final approach introduced here for increasing access to STEM knowledge because of its ability to engage multiple learning styles. This method can create gateways to knowledge for students because of the unique ability of the arts to foster deep engagement, increased retention, and perseverance (Holmes, 2002; Sally Ride Science, 2017). In fact, there is a correlation between arts education and high performing science students (Dhanapal et al., 2014; Holmes, 2002; Peppler & Wohlwend, 2017). To be successful in STEM fields, students will not only require an understanding of STEM, but also curiosity and a creative drive to spark inquiry and seek multiple perspectives (Mansilla & Jackson, 2013; Stevens et al., 2016).

Madagascar is a unique context for innovative STEM education because of its vast array of endemic biodiversity found nowhere else on Earth (Dolins et al., 2009). The education system



in Madagascar focuses primarily on direct instructional techniques such as rote memorization and book learning in formal classroom settings with little focus on the unique biodiversity of the island (Dolins et al., 2009; Venart & Reuter, 2014; Wills et al., 2014). This makes Madagascar an interesting context for outdoor STEM programs that can be paired with and diverge from the direct instruction students receive in school.

Within the current educational model, the number of Malagasy students that pursue a career in scientific fields is low. According to the Ministry of National Education in Madagascar (The Ministry of National Education in Madagascar, 2016; Ministère de l'Enseignement National, 2017), only 3% of young students chose to pursue a career in scientific fields. In addition, data from UNESCO (2018), revealed that the rate of female employment in STEM fields in Madagascar is also low. This is likely because barriers to access persist among low-income communities, students who do not speak colonial languages, special needs communities, people of color, and women (English, 2017; Marrero et al., 2014; Sally Ride Science, 2017). In many countries, including Madagascar, formal education is taught through colonial languages, such as French, which may differ from native Malagasy languages spoken at home causing additional barriers (Wills et al., 2014). Barriers like this are problematic because access assists communities with far-reaching decisions that affect their wellbeing, making obstacles discriminatory acts (Marrero et al., 2014). Increased STEM access through education models that integrate a variety of pedagogical approaches such as the ones described below will positively impact the global community, as diverse global perspectives are crucial for increased knowledge and innovation (Marrero et al., 2014).

It is essential to understand the impacts and benefits of combining a variety of pedagogical approaches in STEM education, as it may provide additional insight on how to create access to STEM fields through real-world and hands-on experiences. While evaluation of STEM interventions may be common for programs implemented in formal schooling (Aslan Efe & Hanas, 2022; George-Jackson & Rincon 2012; Katzenmeyer & Lawrenz 2006), there is generally a lack of evaluation pertaining to education programs conducted outside of the formal school system, especially among countries in the Global South. For this reason, we embrace this challenge in this article as we evaluate Sciencing Out (SciOut) an innovative education program in Madagascar that incorporates the 4 pedagogical components described above: out-of-school STEM learning experiences, student and scientist collaborations, local and international partnerships, and art education. Our aim is to answer the following research question: How does a field program like SciOut help students engage with STEM topics?

Methodology

Case Study

In this article, we present an education program titled SciOut. This program is an initiative of ExploreHome Madagascar, a Malagasy owned, and operated NGO founded in 2018 by by Tsiory Andrianavalona and Niaina Ramihangihajason to link STEM fields with the general public. SciOut is an immersive science education program that incorporates a week-long in-field camping and data collection experience with scientists (Tables 1&2). It creates bridges between skilled practitioners and high school students through field-based experiences. The goal of the program is to introduce students to Madagascar's unique biodiversity and promote continued science learning, while building off of the direct instruction students receive in school (Dolins et al., 2009) (see Appendix A1 for detailed program overview).

Sample Group

Program applications were advertised on social media and in schools throughout and near Antananarivo. 66 applications were submitted. 21 student applicants from 12 public and private schools were selected to participate in one of two program cohorts. There were a majority of female (68.2%) versus male applicants (31.8%). Among the 21 participants selected for the program, 16 were girls (76.2%) and 5 boys (23.8%) (Table 1).

Table 1. SciOut1 (first cohort) & SciOut2 (second cohort) Descriptions

	Duration	Students	Facilitators &	Partner	Location
			Scientists		
	9 days (4 days in	10 malagasy	9 malagasy	SADABE (non-	Mahatsinjo forest
	Antananarivo	students (7	facilitators &	governmental	(Tsinjoarivo-Ambalaomby
	for orientation, 5	girls, 3 boys)	scientists	organization &	New Protected Area). High
	days engaged	14-18 years old	(primatology,	local partner)	altitude rainforest near the
	with hands-on	from 5	entomology, &		Betsimisaraka and Merina
	learning in	different	paleontology) 1		Malagasy communities.
SciOut1	entomology and	schools	international		Home to a diverse range of
	primatology	(private and	collaborator (art		wildlife including 10
	alongside	public)	& science		species of lemurs like the
	scientists while		educator, USA)		critically endangered
	camping in the				diademed sifaka,
	field)				Propithecus diadema
					(Behrens & Barnes, 2016;
					Irwin, 2013a; Irwin, 2013b)



	12 days (5 days	11 malagasy	10 malagasy	GERP (non-	Maromizaha forest-eastern
	in Analavory for	students (9	facilitators &	governmental	highland rainforest that
	orientation &	girls, 2 boys)	scientists	organization &	exists within the
	paleontological	15-17 years old	(paleontology,	local partner)	Ankeniheny-Zahamena
	fieldwork, 7	from 8	ornithology,		forest corridor. Home to 12
	days engaged	different	botany, &		lemur species including the
	with hands-on	schools (public	primatology) 2		greater bamboo lemur,
0.10.10	learning in	and private)	international		Prolemur simus, and
SciOut2	primatology,		collaborators		Madagascar's largest lemur
	ornithology,		(videographer		species, the Indri indri (Sipa,
	botany &		from South		2020).
	ethnobotany		Africa, educator		
	alongside		from Finland)		
	scientists while				
	camping in the				
	field)				

Notes. Descriptions of Program Length, Activities, Students, Facilitators & Scientists, Partners, & Locations.

Program Curriculum

The field sites added to the authenticity of the experience as students adapted to the changing weather patterns, participated in hikes through different terrain, and followed the movements of the species they observed (Houseal et al., 2014).

Table 2. SciOut1&2 Curriculum Description

	Pre-field: Facilitators & Scientists	Pre-field: Students	SciOut1&2: Field Work	Post-field:
SciOut1 &2	Knowledge exchange workshop (1 month prior to the program). 3 days at field sites (learning campsite, species, & developing activities). 1 day participating in a sciencetelling workshop in	Orientation meeting for students & parents (1 week prior). Pre-field orientation (during program): lectures about STEM career fields, art education & science learning	The outdoor out-of-school learning setting provided opportunities for students to experience science in the field alongside skilled practitioners through student & scientist collaborations. Participatory learning and inquiry-based education methods were used to spark curiosity. Field courses enabled students to learn about science methodology through authentic data collection as they	Students' sciencetelling videos were edited and finalized postfield by program staff. The results are 22 videos (20 individual student videos and 2 group videos). Some were aired during the final gathering for the



Antananarivo (discussions about engaging high school learners). (creative process and scientific method), field life, videography, & photography contributed to ongoing research while studying Madagascar's endemic flora and fauna.

Each session included education about reforestation, biodiversity monitoring, primate behavior, habitat threats, data collection techniques, studies of past environments and extinct animalssuch as the pygmy hippopotamus (lalomena in malagasy), Hippopotamus lemerlei, a focal point of malagasy tales. Participants had the opportunity to dig, touch, and see paleontological field work first hand. Students were also involved in inquiry among the local people through ethnobotany. Using project-based learning, both cohorts applied the storytelling techniques taught during the orientation to document their experience in the forest. They created short videos to broadcast the value of science from their perspective.

first cohort. All were aired online using ExplorerHome's website and social media platforms (Instagram, Facebook, & Youtube). The videos were also aired during an international event, PaleoFest 2020 (Burpee, Illinois, 2020).

Notes. Descriptions of Pre-field work, Field work, & Post-field work.

Activity Description: A typical SciOut field-day

Students, facilitators, and scientists wake-up in their tents after camping in the forest for the night. Everyone prepares for the day as breakfast is served. After breakfast, students are divided into teams. Each team is paired with a scientist and participates in different activities while hiking and exploring the natural area. During SciOut1, those activities included radio tracking, observing lemurs with ethnographic/animal behavior charts, transect studies, and identifying insects. During SciOut2, those activities included a paleontology dig-digging a field plot, safely uncovering subfossils, cleaning, and protecting the found fossils. SciOut2 teams also observed lemurs in the wild and participated in "botanical plot" methodology using decameters, compasses, and measuring instruments to develop quadrants. Students used dictaphones and binoculars to assist with their ornithology studies of bird behavior while creating Mckinnon's



lists. They conducted interviews with local people and learned about ethnobotany and medicinal

Each team returned to camp for lunch. Afterwards students had free time to work on their video projects, journal, sketch, and get to know one-another. Presentations from facilitators and scientists commence in the afternoon as they share relevant topics related to the morning's field observations and camplife topics-how to live with mosquitoes in the field, life as a woman doing scientific field work, and/or updates about their video projects and next day schedules. At night, the group participates in night hikes, campfire activities-games, songs, and skits-before going to sleep in their tents and beginning a similar schedule the next day.

Data Collection

We developed an evaluation study to gather quantitative data to understand how a field program like SciOut helps students engage with STEM/STEAM topics. We used three data collection tools: pre & post-program student questionnaires, student video evaluations, and facilitator & scientist post-program evaluations. Both the questionnaires and the video evaluations were structured to understand how SciOut helped students engage with STEM topics. For that, we measured three aspects: i. student interest, ii. academic achievement, and iii. understanding of STEM/STEAM topics. The qualitative feedback from open-ended responses was used to emphasize and explain different quantitative data points.

The study received approval from The Ethical Board of Miami University of Ohio. Parental consent was obtained for SciOut students. Participants were given the option to answer or opt out of each survey question. As a result, some students choose not to answer all of the questions. A potential limitation of the study may be social desirability bias. Students may have altered their responses to satisfy program facilitators and scientists, which could have impacted how they responded to particular questions. For this reason, we used different tools such as anonymous pre and post-surveys and a video evaluation to test the same criteria.

To ensure the validity and reliability of this study, we embraced some of the strategies advocated for by Shenton (2004). The pre and post-program evaluation questions were modeled after well-established methods and previous studies with modifications to match the unique characteristics of the SciOut program (RK&A Learn With Us, 2018). The co-authors and founders of SciOut were familiar with the program as its creators as well as the learning context the program was facilitated in. They provided input and feedback as the evaluation tools were developed. We utilized triangulation by using different evaluation methods such as student pre & post-program evaluations, facilitator post-program evaluations, and video evaluations. To encourage honest responses from participants, the evaluations were anonymous. This study is not measuring for or demonstrating academic success, but instead seeking to understand the



impacts of the program on students, and how it helped students engage in STEM topics. We described the program and study in detail so it can be replicated.

Student Pre/Post-Questionnaires n=21

The SciOut1 program and evaluation was conducted in April 2019, and SciOut2 in September 2019. The pre and post-program evaluations were identical and included 17 Likert scale questions that asked students to rate their responses to question as 1-Strongly disagree, 2-Disagree, 3-Slightly disagree, 4-Undecided, 5-Slightly agree, 6-Agree, 7-Strongly agree. The pre-program written evaluations were facilitated on the first day of each program before students engaged in STEM activities. Post-program evaluations were implemented on the final day of each program. Of the 21 students that participated in total, 21 completed the written survey (100% response rate), however some chose not to answer every question. The pre and post-program surveys were unpaired to maintain anonymity among the research participants. As a result, only the mean and standard deviation could be calculated as statistical tests. The pre and post-program evaluation questions focused on the following topics:

- (1) *Interest:* Defined as a active learning: discussion and/or physical engagement with a learning activity, b. student driven work: project driven by a student question or curiosity, and c. collaboration: peer discussion and or combined work/research (Lai, 2018; Mansilla & Jackson, 2013; Paris et al., 1998; Stevens et al., 2016).
- (2) Academic Achievement: Defined as a. analysis: comparing and contrasting, b. comprehension: application of knowledge, c. critical thinking: questioning and criticizing information, d. knowledge: finding important points (Lai, 2018; Mansilla & Jackson, 2013; Paris et al., 1998; RK&A Learn With Us, 2018).
- (3) *Understanding of STEM/STEAM topics:* Defined as a. interdisciplinary learning: connecting different subject matter and/or combining different processes (ex: creative and scientific process) (Lai, 2018; Mansilla, 2016).

The open-ended question asked students to explain their response after selecting how likely they are to recommend this program to their peers (see Appendix A2 for evaluations).

Percentages were calculated for the response rates for each question to show the comparisons between pre and post-program survey responses. Means were calculated to measure the differences from pre and post-program survey results. The standard deviation (STDV) was calculated to measure how people naturally vary from each other from pre to post-program results. All open-ended responses were categorized using the study domains.

Student Videos n=20

Participants were equipped with smartphones, selfie sticks, microphones, basic free editing software (Adobe Clip), and instruction to create 1–2-minute videos using artistic skills in

storytelling, videography, and photography. This project was student-directed and incorporated participatory learning methods by emphasizing student voice as they described a science theme of interest from their field experience to share with their communities. During SciOut1, the instruction focused heavily on field work over storytelling and videography. Students recorded their footage in the field and ExplorerHome staff completed the video editing post-program. During SciOut2, the students' time was equally divided between field work and storytelling and included the assistance and instruction from a professional storyteller and videographer. The students recorded their footage and completed the editing process in the field. ExplorerHome staff added only subtitles, background music, logos, and lighting adjustments (see Appendix A3 for video playlists). Of the 21 students, 20 completed the requirements for the video project.

An evaluation rubric was used to assess the student videos (see Appendix A4 for rubric). The rubric included 3 domains: i. student interest, ii. academic achievement, iii. understanding of STEM/STEAM topics. Each domain has 4 areas of measurement, and each area is valued on a scale of 4 in terms of performance. 2 evaluators evaluated each video separately and compared their results to ensure accuracy. The evaluators collaboratively re-evaluated any score that resulted in a 3-point difference for the same area of measurement in a domain. The rubric assessed the following qualities:

- (1) *Interest:* Defined as, a. wonder, b. imagines or envisions possibilities, c. encourages the audience to wonder about a STEM/STEAM topic.
- (2) Academic Achievement: Defined using the same indicators as the student pre/post-questionnaires with the addition of, a. uses evidential reasoning.
- (3) *Understanding of STEM/STEAM topics*: Defined using the same indicators as the student pre/post-questionnaires with the addition of, a. connects program experience to interdisciplinary learning in school, b. connects the interdisciplinary knowledge learned to daily life.

A percentage was calculated using both sets of scoring from the evaluators for each area of measurement in a domain.

Facilitator & Scientists Post-Program Evaluations n=12

Post-program written evaluations were administered on the final day of each program to gather feedback from the facilitators and scientists (see Appendix A5 for evaluations). This survey included 9 Likert scale questions, and 7 open-ended questions to uncover the facilitator and scientist objectives for student learning, methods of student engagement, program impacts, their favorite aspects of the program, challenges, and recommendations. Of the 12 facilitators and scientists, 12 completed the written survey (100% response rate).

The median response scores from the facilitator and scientist Likert scale questions were calculated and summarized. All open-ended responses were categorized using the study



domains i. interest, ii. academic achievement, iii. understanding of STEM/STEAM topics. The open-ended responses from facilitators were used to enrich the results of the student evaluations in this report. The rest of the data can be found in the Appendix B.

Results

The evaluation results are structured to help us learn how SciOut helped students engage with STEM/STEAM topics by measuring student interest, academic achievement, and understanding of STEM/STEAM topics. For each of these three aspects measured, we present the results relating to the pre/post-questionnaire and the video evaluation. Additionally, we introduce at the end some responses from the student and facilitator evaluations.

Student Interest

Table 3 shows a general trend in the mean which increases from pre to post-test except for Question 4, "I am bored when I study science". Question 4 is reversed in comparison with the other questions meaning a decreased mean from pre to post-test indicates that some students determined they were not bored when studying science during the program.

Table 3.

Program Objective 1. Interest

					Strongly	gly											Strongly	ly
					Disagree	ree											Agree	
Student Questions	M	Mean	SD	Q	1		2	2	3		4		5		9		7	
	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post
Q3: Science is interesting.	6.3	8.9	.49	.35			,		•						61	14	38	85
Q4: I am bored when I study	1.5	1.4	.87	.74	52	99	33	28	4	,	4	4						,
science.																		
Q5: Science is hands-on.	5.9	6.7	76.	.43	ı	ı	i	ı	ı	ı	6	i	19	,	38	23	33	92
Q6: I use science every day.	9	6.5	77:	.51									28		42	47	28	52
Q7: I have completed science	4	5.3	1.8	1.7	4		33	4			14	14	23	6	14	28	6	33
projects with other students.																		
Q8: I can learn more about my	9	6.3	1.2	.85	ı	ı	4	ı	ı	ı	4	4	4	6	42	33	42	52
classmates and science by listening																		
to them talk about it.																		
Q9: Science can help me	5.7	6.5	1.6	.59	ı	1	ı	ı	,	ı	6	ı	14	4	38	33	33	61
understand myself better.																		
Q10: To understand more about	6.1	6.1	_	86.	ı			ı		ı	14	6	4	6	33	33	47	47
science, it is better to have																		
someone tell me.																		
a science or	6.4	9.9	.67	.57	ı	ı	ı	ı	1	1	ı	1	6	4	33	23	57	71
STEM/STEAM career																		
					I will not	not	I may		Neutra]	al	I will		I will					
													highly					
	Ĭ	Mean	\mathbf{SD}	Q	1		2		3		4		S					
	pre	pre post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post				
Q19: How likely are you to		4.4 4.7	.67	.56				ı	6	4	38	19	52	92				
recommend this program to your																		
peers?																		

peers'. Note. Mean, STDV, and Percentage Response Scores For SciOut1&2 Student Pre & Post-Program Evaluation Questions 3-11&19 On A 7- Point Likert Scale



Table 4. *Program Objective 1. Interest*

Measuring Student Interest	1	2	3	4
	No Achievement	Emerging	Developing	Accomplished
Wonders: The student describes facts and observations related to a topic of interest and includes the who, what, when, where, and why. (SciOut1/SciOut2)	-	22% / 18%	33% / 27%	44% / 54%
Imagines or envisions possibilities: The student demonstrates how they imagined/or thought up possible solutions to the concept in question by describing their thought process. Videos and photographs not included in this section, only descriptions. (SciOut1/SciOut 2)	83% / 27%	16% / 22%	0% / 4%	0% / 45%
Encourages the audience to wonder about a STEM/STEAM topic: The student uses dynamic storytelling to present a STEM/STEAM topic to spark interest and wonder. (SciOut1/SciOut 2)	0% / 0%	16% / 9%	61% / 22%	22% / 68%
The student is involved in, or describes a physical action related to the topics discussed: The student clearly describes a methodology or subject. Or the student shows a physical action related to the methodology or subject described. (SciOut1/SciOut2)	61% / 22%	11% / 13%	27% / 13%	0% / 50%

Note. Percentage of Evaluator Scores For SciOut1&2 Student Videos.

Table 4 reveals a high percentage of performance on the value scale, accomplished (44%/54%) in the area measuring for "wonder". It also identified a high percentage of performance on the value scale, developing (61%/22%) and accomplished (22%/68%) in the area measuring for, "encourages the audience to wonder about a STEM/STEAM topic". In general SciOut2 students scored higher percentage points on the value scale, accomplished in comparison to SciOut1 students. SciOut1 students scored higher percentage points on the value scale, no achievement in comparison to SciOut2 students.



Academic Achievement

Table 5.

Program Objective 2. Academic Achievement

					Strongly	ıgly											Strongly	sly
					Disagree	gree											Agree	
Student Questions	Ĭ	Mean	S	Q		1	- •	2		3	4		ıc	10		9	7	
•	Pre	Pre post	pre	post	pre	pre post		pre post pre post pre post	pre	post	pre	post		pre post	pre	post	post pre	post
Q12: Science can help me	5.9	9.9	1.4	49						,			6		22	38	28	61
understand what life was																		
like a long time ago.																		
Q13: Science can help me	6.2	6.5	.76	.51	•	•	•	•	•	•	4	•	4	•	52	47	38	52
understand life today.																		
Q14: All people should	3.5	4.5	1.8	2.1	4	6	28	14	6	14	6	4	33	6	4	23	4	23
understand science in the																		
same way.																		
Q15: Science can help me see	5.9	6.7	.97	.43	ı	ı	ı	ı	ı	ı	6	ı	19	ı	38	23	33	2/9
something familiar in a new																		
way.																		

Note. Mean, STDV, and Percentage Response Scores For SciOut1&2 Student Pre & Post-Program Evaluation Questions 12-15 On A 7- Point Likert Scale.

ISSN: 2149-8504 (online) © i-STEM 2015-2023, j-stem.net



Table 6.

Program Objective 2. Academic Achievement

Measuring Academic Achievement	1	2	3	4
	No Achievement	Emerging	Developing	Accomplished
Uses evidential reasoning: The student describes, demonstrates, or shows the evidence they used to come to their reasoned conclusion. Include the use of photos and videos as evidential reasoning. (SciOut1/SciOut2)	-	16% / 4%	55% / 22%	27% / 72%
Comparing and contrasting: The student compares and contrasts different information. The scale depends on how much comparing and contrasting is accomplished in comparison with other videos. (SciOut1/SciOut2)	27% /9%	38% / 27%	22% / 22%	11% / 40%
Application of knowledge: The student applies the new knowledge that they learned from SciOut by describing it in the video. (SciOut1/SciOut2)	83% / 31%	16% / 18%	- / 9%	- / 40%
Questioning and criticizing information: The student delves deeper into the content by asking questions like: "Why is that? Where is the evidence? How good is that evidence? Is this a good argument? Is it biased? Is it verifiable? What are the alternative explanations?" (SciOut1/SciOut2)	100% / 81%	- / 4%	- / 13%	-

Note. Percentage of Evaluator Scores For SciOut1&2 Student Videos.

Table 6 reveals a high percentage of performance on the value scales developing (55%/22%) and accomplished (27%/72%) in the area measuring for, "uses evidential reasoning". The video evaluation showcased a high percentage of no achievement (83%/31%) in the area measuring for "application of knowledge". It also revealed a high percentage of no achievement (100%/81%) in the area measuring for "questioning and criticizing information" (Table 6). In general SciOut2 students scored higher percentage points on the value scale, accomplished in comparison to SciOut1 students. SciOut1 students scored higher percentage points on the value scale, no achievement in comparison to SciOut2 students.



Understanding of STEM/STEAM Topics

Program Objective 3. Understanding of STEM/STEAM Topics

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Student Questions	X	Mean	(Ü		1	2		3		4		īC		9			
	pre	pre post pre	pre	post	pre	post	pre	pre post pre post pre post pre post pre post	pre	post	pre	post	pre	post	pre	post	pre	post
Q16: Science problems that are 4.2 3.2	4.2	3.2	1.9	2	4	19	14	33		4	28	14	6	6	33	6	4	6
complicated make me nervous.																		
Q17: Science can give me new 6.5	6.5	9.9	9.	.58	•	,	•		ı	,	,	,	4	4	38	28	22	99
ideas.																		
Q18: I use different subjects 5.9	5.9	6.2	1.1	1.2	•	•	4	4	1	ı	1	4	23	ı	38	33	33	57
(math, technology, art) when																		
learning science.																		

Note. Mean, STDV, and Percentage Response Scores For SciOut1&2 Student Pre & Post-Program Evaluation Questions 16 & 18 On A 7- Point Likert Scale.

Table 7 presents a general trend in the mean which increases from pre to post-test except for Question 16, "Science problems that are complicated make me nervous". Question 16 is reversed in comparison with the other questions meaning a decreased mean from pre to post-test indicates that some students determined that complicated science problems did not make them nervous after participating in the program.



Table 8. *Program Objective 3. Understanding of STEM/STEAM Topics*

Measuring student understanding of

STEM/STEAM topics				
-	No Achievement	Emerging	Developing	Accomplished
Connects different subject matter: Example: The student discusses a connection between human anatomy and primate anatomy. But if the student had compared different types of primate anatomy, it would not count as connecting different subject matter. (SciOut1/SciOut2)	50% / 59%	38% / 9%	11% / 13%	- / 18%
Combines different processes (ex: creative and scientific process): A process is the different steps that a scientist, engineer, artist, or mathematician uses to arrive at a goal. The student combines different processes to reach a conclusion. (SciOut1/SciOut2)	94% / 54%	5% / 22%	-	- / 22%
Connects program experience to interdisciplinary learning in school: Example: The student makes direct connections to subjects taught in school by explicitly stating something like, "we learned about this in school, but while observing it in the wild, we learned more about it." (SciOut1/SciOut2)	100% / 100%	-	-	-
Connects the interdisciplinary knowledge learned to daily life: The student explains how this knowledge connects to daily life and describes why it is important to know, and care about it. (SciOut1/SciOut2)	27% / 18%	61% / 36%	11% / 18%	- /27%

2

3

Note. Percentage of evaluator scores for SciOut1&2 student videos.

Table 8 revealed a high percentage of no achievement (94%/54%) in the area measuring for, "combines different processes", as well as a high percentage of no achievement (100%/100%) in the area measuring for "connects program experience to interdisciplinary learning in school" (Table 8). In general SciOut2 students scored higher percentage points on the value scale, accomplished in comparison to SciOut1 students. Both SciOut1 and SciOut2 students scored high percentage points on the value scales measuring for, no achievement and emerging.



Student & Facilitator Open-ended Responses:

Some of the student open-ended responses are paraphrased below:

The program helps teens follow their dreams and provides direction for future career paths. SciOut teaches science that is not taught in classrooms, offers opportunities to interact with others and embark on new experiences. It changes one's thinking process and inspires participants to share the importance of scientific subjects with friends.

The students learned that science can help them understand things more deeply. Some understood more about living forms on earth and how to protect them as a result of the program. The students indicated that the program enabled them to see life in a different way. Participants learned that science helps them understand life from the past, the present, and the future. The students were able to understand science better through fieldwork.

Some of the facilitator open-ended responses are paraphrased below:

A facilitator/scientist explained the importance of exposure to hands-on field work, alongside experts, by explaining how this increased their own interest in STEM as a young student. They go on to explain how this enables participants to visualize themselves in STEM career fields.

The facilitators and scientists describe how they noticed students change throughout the program. The student participants became more curious, asked more questions, and noticed more as their observation and critical thinking skills developed.

The opinions of youth enabled them to think about their own learning methods. The facilitators and scientists transmitted their knowledge, but also learned much from the students.

Increasing the visibility and accessibility of STEM careers to school children is of the utmost importance. SciOut impacts not only the intellectual behavior but also the mindset of the participant through deep skill exchange between the students and the rest of the team. Many students remarked on what a great experience it was to actually be with scientists in the field, to see what their daily activities consist of instead of just learning about it in a classroom. SciOut allows students to discover the unique biodiversity of their country and be proud of it.

Discussion

Our results illustrate how a field program like SciOut helps students engage with STEM topics. In general, we found an increase in the metrics that were measured for related to the three topics: i. Student interest, ii. Academic achievement and, iii. Understanding of STEM/STEAM topics. Next, we discuss to what extent these results may be connected to the pedagogical approaches used in SciOut.



Some students indicated that they were less bored with science topics and understood how science is used in daily life after participation. This may be a result of the experiential outof-school learning environment which gave students first-hand encounters with the theoretical concepts they learn in school. Evidence of experiential learning may be seen in the increase of students that strongly agreed with the statement, "science is hands-on", from the pre-test (percentage: 28%; mean: 6; STDV: .70) to the post-test (percentage: 61%; mean: 6.7; STDV: .43) (Table 3). This experiential component may have increased the number of students that strongly agreed with the statement, "I am interested in a science or STEM/STEAM career", from the pretest (percentage: 57%; mean: 6.6; STDV: .57) to the post-test (percentage: 71%; mean: 6.6; STDV: .57) (Table 3). These outcomes may reveal that access to out-of-school learning environments can provide important experiential, and hands-on encounters with theoretical concepts to nurture interest in STEM topics. These results support previous studies that describe how outof-school learning and experiential learning are linked to increased student motivation for learning science (Paris et al., 1998; Yildirim 2020). The video evaluation revealed a high percentage of performance on the value scale, accomplished (44%/54%) in the area measuring for "wonder" (Table 4). Inquiry education methods tied to experiential learning were used to spark curiosity among students throughout the program. This may have impacted their ability to wonder about a subject and encourage others to do the same through their sciencetelling videos.

In their open-ended responses, participants mentioned the significance of *student and scientist collaboration* by noting how thrilled they were to learn from scientists in the field and emphasized the impact of observing and partaking in the daily activities of a field scientist as opposed to classroom learning only. Additional evaluation studies of education programs have identified a correlation between out-of-school experiences, mentorship/interaction with experts, and increased student interest in STEM topics (Houseal et al., 2014; Stevens et al., 2016). The student's open-ended responses indicated that opportunities to interact with others while learning was important, which is connected to increased understanding and knowledge retention (Alters & Nelson, 2002). This may also explain why students indicated that they were less intimidated by complicated science problems after participation.

SciOut was developed and facilitated by Malagasy science professionals and taught in Malagasy language. Throughout the program, Malagasy science experts mentor Malagasy students. This enabled participants to see themselves represented in STEM careers, which can increase engagement (Sally Ride Science, 2017). Implementing culturally responsive programs, like SciOut, that are connected to local partnerships, experts and biodiversity topics is likely to increase global STEM access which is essential for the sustainability of human communities and natural ecosystems (Kant & Burckhard, 2018; Stevens et al., 2016). The international partnerships provided opportunities for an exchange of knowledge, culture, and language.



SciOut incorporated arts with the use of sciencetelling videos that were created to instill a broader interest in STEM beyond program participants. Storytelling was used to broadcast the value of science from the student's perspectives as they shared their stories using their native Malagasy language (translated to English subtitles). This included the use of videography, photography, and in some cases drawing to portray a dynamic STEM story of personal interest to share with their communities. Thanks to those videos, students not only understood how *arts education* is beneficial to STEM learning, but implemented the concept within their sciencetelling video projects. The inclusion of arts education in STEM offers far-reaching implications for global sustainability by empowering students to think beyond limiting societal structures towards out-of-the-box solutions, which they will be required to do in order to solve the challenges of their future (Bequette & Bequette, 2012).

In this sense, the video analysis uncovered an increased percentage of accomplishment in the areas that were evaluated among SciOut2 participants. This may indicate that the different instructional approaches between SciOut1 (increased instructional focus on fieldwork over storytelling/videography) and SciOut2 (equal instructional focus between fieldwork and storytelling/videography) impacted the video products. Future programs could incorporate equal instruction to create impactful videos that not only engage student participants, but also their surrounding communities.

The general increasing trend that can be seen in the mean on the student pre & post-program evaluations with support from the student, facilitator and scientist open-ended response comments seem to indicate that the experiential out-of-school learning, student and scientist collaborations, connection to local biodiversity and expertise, and art (videography, photography, and storytelling) components of SciOut helped students engage with STEM topics. However, we would also like to acknowledge that the data shows that pretest numbers in the questionnaire were already high. This could indicate that the SciOut program attracted students who had a strong interest in STEM prior to participating.

Study limitations & Future Recommendations

We acknowledge some limitations in the design of the video evaluation rubric. The video evaluation showcased a high percentage of no achievement (83%/31%) in the area measuring for "application of knowledge". It also revealed a high percentage of no achievement (100%/81%) in the area measuring for "questioning and criticizing information" (Table 6). The SciOut1/SciOut2 video evaluation also revealed a high percentage of no achievement (94%/54%) in the area measuring for, "combines different processes", as well as a high percentage of no achievement (100%/100%) in the area measuring for "connects program experience to interdisciplinary learning in school" (Table 8). This indicates a weakness in the evaluation tool



as these aspects were not a part of the project goals or instruction, which likely explains these results.

Recommendations for future studies include in-person interviews with students' months after the program to understand the long-term benefits of SciOut. Future evaluation methods could incorporate paired pre and post-program evaluations to track individual student progress and identify significant results through statistical tests.

Recommendations for Education Models

Both the students, facilitators, and scientists indicated that programs like SciOut have lasting impacts and assist participants with achieving their professional career goals. Incorporating these four innovative pedagogical approaches is likely to foster motivation and perseverance within students to pursue STEM careers and contribute to a sustainable world (Paris et *al.*, 1998; Stevens et *al.*, 2016). We next provide further recommendations on how these pedagogical approaches could be incorporated in future STEM projects.

Out-of-school learning can be applied to multiple education settings by assessing what alternative learning environments exist nearby. Incorporating this component may include field trips to established informal education institutions like museums, science centers, and parks. However this component can also be meaningfully crafted through alternative resources like empty lots, open outdoor spaces, or even imaginary field trips that involve conscientious role play and transforming the classroom into another environment.

The facilitators and scientists indicated that SciOut allowed students to discover the unique biodiversity of their country and be proud of it. STEM education programs should be tailored to fit the cultural context that students identify with and include similar representation among STEM teaching professionals. *Student and scientist collaborations* and *local and international partnerships* can be applied to multiple education settings through networking and inquiries with informal STEM education institutions, local grass-roots environmental justice groups, artist activists, and STEM facilities. Also, consider researching STEM professionals on National Geographic's Explorer Directory and networking on LinkedIn and social media. Proposals could include approaching science professionals about presenting as guest speakers, participation in citizen science, or deeper collaborations where scientists participate as research advisors/mentors to student work.

Existing challenges to incorporating *arts education* into different learning environments may include budgets, supplies, and time. Consider using these constraints as opportunities for creative thinking and innovation. What can students create with what they have, and what will they learn in the process?



Acknowledgements

We wish to thank Sciencing Out ExplorerHome staff and facilitators: Sarizafy Harifetra, Andrianavalona Zoly, Andrianasolo Vina, Antsariravaka Holimandimby, Kevin Safidinirina, Shivan Parusnath, Kanto Rafidison. We wish to thank the Sciencing Out Scientists Naina Rabemananjara, Manitra Andriambelomanana, Rindra Nantenaina, Nadia Rasolofomanana, Stéphanie Razakaratrimo, Ravoniaina Rakotozandry.

We wish to thank the participating students and their families. We also wish to thank the NGO SADABE, ExplorerHome Madagascar's longtime partner, and GERP Madagascar for permitting us to conduct the Sciencing Out science camp in the NAP of Tsinjoarivo-Ambalaomby and Maromizaha.

This evaluation study was conducted as part of graduate work through Miami University of Ohio. The authors wish to thank professors Katie Feilen, PhD, Debbie Clemens, and Kevin Matteson, PhD. This work would not have been possible without the support of the National Geographic Education team.

The Sciencing Out program was funded by the National Geographic Society under Grant NGS-51954E-18.

Human Subject Research: This study was approved by Miami University's Human Subjects Internal Review Board. It is in compliance with ethical standards.

Conflict of interest: 2 authors are the co-founders of ExplorerHome Madagascar Science Center and the creators of Sciencing Out. 1 author assisted with the development of Sciencing Out. As a result, we could be more inclined to explain the positive results of the program.

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Appendix A

A1._Detailed Program Overview of SciOut1&2:

• <u>Scientifiques en herbe avec le programme « Sciencing Out » – ExplorerHome Madagascar</u> Science Center

A2. Student Pre and Post-Evaluation:

The purpose of this research is to examine the student impacts of immersive STEM/STEAM (Science, Technology, Engineering, Art, and Engineering) education programs. This research is being conducted as part of the graduate degree program of Susan Dorsey and the Principal Investigator of "Sciencing Out", Tsiory Andrianavalona, PhD.

Products from the event such as student evaluations, observations, and videos from "Sciencing Out" will be analyzed. Students will work with a videographer and produce a 2-minute video of their experiences to be shared through the ExploreHome website and social media. The researchers will review the video and take notes about how the students react to the activities. Evaluative data from the videos will not be linked to individual identities. Only the researcher, principal investigator, and faculty advisor will have access to individual responses and results of the survey will only be presented publicly as aggregate summaries.

What are your feelings about science (circle one):

Fascinated, Good, Bored, Uncomfortable

Have you taken a science class in school in the past 2 years (circle one):

Yes, No, Unsure

Circle your responses to the statements below on a 7-point scale:

(1)Strongly disagree, (2)Disagree, (3)Slightly disagree, (4)Undecided, (5)Slightly agree, (6)Agree, (7)Strongly agree

Science is interesting.

I am bored when I study science.

Science is hands-on.

I use science every day.

I have completed science projects with other students.

I can learn more about my classmates and science by listening to them talk about it.

Science can help me understand myself better.

To understand more about science, it is better to have someone tell me.

I am interested in a science or STEM/STEAM career.



Science can help me understand what life was like a long time ago.

Science can help me understand life today.

All people should understand science in the same way.

Science can help me see something familiar in a new way.

Science problems that are complicated make me nervous.

Science can give me new ideas.

I use different subjects (math, technology, art) when learning science.

How likely are you to recommend this program to your peers?

(1)I will not recommend, (2)I may recommend, (3)Neutral, (4)I will recommend, (5)I will highly recommend

Please explain your response below:

A3. Video Playlists:

SciOut1 Youtube Playlist:

https://www.youtube.com/playlist?list=PLELP2HqoIAdWXwKAEIbU6kewYSl9HlYht SciOut2 Youtube Playlist:

https://www.youtube.com/playlist?list=PLELP2HqoIAdUxagwQL-1ECd9-Se8Hdd-n

A4. Student Video Evaluation Rubric:

High school students who complete the "Sciencing Out" program will work with a videographer to develop scienctelling videos of their experience which will be shared with their communities. The student videos will be evaluated to determine if the program increased student interest, academic achievement, and understanding of STEM/STEAM topics. The four-level rubric below will be used to measure if student interest is reflected in the videos. Evaluators will record notes to identify what evidence was observed to justify ratings.

1=No Achievement:

- The student does not wonder about a STEM/STEAM subject.
- The student does not **envision possibilities**.
- The student does not encourage the **audience to wonder** about a STEM/STEAM topic.
- The student is not involved in a **physical action** related to the topics discussed.

2=Emerging:

- The student **wonders** minimally about a STEM/STEAM subject. Questions are mostly limited to who, what, when, or where and do not include why.
- The student shares a limited amount of information on **envisioned possibilities** without detail.
- The student briefly encourages the **audience to wonder** about a STEM/STEAM topic with little detail.



 The student is briefly shown engaging with, or minimally describes a physical action related to the topic, but does not describe how the action relates to the STEM/STEAM topic discussed.

3=Developing:

- The student **wonders** moderately about a STEM/STEAM subject while exploring the "why" behind a topic, however the "why" questions don't connect to a central theme.
- The student shares a moderate amount of information pertaining to **envisioned possibilities**, but does not connect to a central theme.
- The student encourages the audience to extensively wonder about a STEM/STEAM topic through multiple questions or descriptions, but neglects to explain their significance to the subject.
- The student is shown engaging with, or describes a physical action related to the topics, but does not explain how it increased their understanding of STEM/STEAM topics.

4=Accomplished:

- The student wonders extensively about a STEM/STEAM subject while exploring the "why" behind a topic and connects it to a central theme.
- The student shares an extensive amount of information pertaining to **envisioned possibilities**, while connecting to a central theme.
- The student encourages the audience to extensively wonder about a STEM/STEAM topic through multiple questions or descriptions and explains its connection to the central theme.
- The student is shown engaging with, or extensively describes a **physical action related** to the topic and explains how it increased their understanding of STEM/STEAM topics.

Measuring Student Interest

2 3 4

1

Wonders: The student describes facts and observations related to a topic of interest and includes the who, what, when, where, and why. Example: The student explains reasons why humans and lemurs are similar (opposable thumb), and different (furry, face, feet), and explains what the adaptations help each to do.

Imagines or envisions possibilities: The student demonstrates how they imagined/or thought up possible solutions to the concept in question by describing their thought process. Do not include videos and photographs in this section, only descriptions. Example: "I wondered why the bird was making that sound. I observed it doing...and based on my previous knowledge of this species, or the knowledge that the guide shared, I determined it made this sound because..."

Encourages the audience to wonder about a STEM/STEAM topic: The student uses dynamic storytelling to present a STEM/STEAM topic to spark interest and wonder. Example: There is a clear guiding thread throughout the video. The student describes how muddy the path was allowing the audience to be part of the process.



The student is involved in, or describes a physical action related to the topics discussed: The student clearly describes a methodology or subject. Or the student shows a physical action related to the methodology or subject described. Example: The student describes the differences between lemurs and humans. We follow the student through all the steps as they physically do them while they describe the process. The student shows what it means to have an opposable thumb and a muzzle through body motions.

The four-level rubric below will be used to measure if student academic achievement is reflected in the videos. Evaluators will record notes to identify what evidence was observed to justify ratings.

1=No Achievement:

- The student provides no **evidential reasoning** to explain a claim.
- The student does not **compare and contrast** information.
- The student neglects to highlight important points or findings, and does not **apply new knowledge** to other knowledge.
- The student demonstrates no evidence of critical thought but accepts claims without questioning.

2=Emerging:

- The student provides a vague description of relevant **evidential reasoning** with little detail and no connection to a central theme.
- The student briefly **compares and contrasts** knowledge, while highlighting some important points, but offers little detail and no connection to a central theme.
- The student **applies some knowledge** to other knowledge, but neglects to describe how it connects in detail.
- The student demonstrates some **critical thought** by **questioning** new knowledge. Questions are mostly limited to who, what, when, or where and do not include why.

3=Developing:

- The student provides mostly relevant evidential reasoning to explain a claim, however the response lacks detail, is somewhat vague, and does not clearly describe its connection to a central theme.
- The student **compares and contrasts** knowledge, while highlighting important points using detail with a vague connection to a central theme.
- The student shows evidence of **applying knowledge** to other knowledge and vaguely describes how it connects.
- The student demonstrates **critical thought** by **questioning** new knowledge and exploring the "why" behind a claim, while vaguely explaining alternative possibilities.

4=Accomplished:

- The student provides relevant **evidential reasoning** to explain a claim in detail and clearly describes its connection to a central theme.
- The student **compares and contrasts** knowledge and highlights important points using detailed descriptions that clearly connect to a central theme.

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- The student demonstrates skill in **applying knowledge** to other knowledge, while clearly describing a connection.
- The student uses critical thought to question new knowledge and explores the "why" behind a claim, while clearly explaining alternative possibilities.

Measuring academic achievement

1 2 3 4

Uses evidential reasoning: The student describes, demonstrates, or shows the evidence they used to come to their reasoned conclusion. Include the use of photos and videos as evidential reasoning. Example: "The bird was building a nest. I concluded it was building a nest because I saw it flying around, gathering twigs, and bringing it back to add to its developing nest." The student uses some photos, but they are not examples of what the student explains (although that is probably because it is hard to find a photo or video of lemurs fighting). The student presents photos of the lemurs that support the statement that they are making, e.g. feet able to hold branches, but does not explain the process or reasoning.

Comparing and contrasting: The student compares and contrasts different information. The scale depends on how much comparing and contrasting is accomplished in comparison with other videos. Example: The student compares and contrasts human anatomy with lemur anatomy. The student presents different explanations on why the male is dominant but does not compare it with the role of the female.

Application of knowledge: The student applies the new knowledge that they learned from SciOut by describing it in the video. Example: "I learned how to conduct a scientific study of birds in the forest with a local guide and ornithologist during SciOut and saw...in the field as a result."

Questioning and criticizing information: The student delves deeper into the content by asking questions like: "Why is that? Where is the evidence? How good is that evidence? Is this a good argument? Is it biased? Is it verifiable? What are the alternative explanations?"

The four-level rubric below will be used to measure if student understanding of STEM/STEAM topics is reflected in the videos. Evaluators will record notes to identify what evidence was observed to justify ratings.

1=No Achievement:

- The student does not describe a connection between different subject matter, or apply knowledge from one discipline to another.
- The student does not describe a **connection between different subject areas or processes** (ex: creative and scientific processes).
- The student does not make a **connection between** the knowledge learned through participation in "Sciencing Out" and **different topics taught in school**.
- The student does not explain how the interdisciplinary knowledge learned through the program connects to daily life.



2=Emerging:

- The student describes some **connection between different subject matter**, but does not apply knowledge from one discipline to another.
- The student **describes different subjects and processes**, but does not describe a connection between them.
- The student describes a vague **connection between** the knowledge learned through participation in "Sciencing Out" and **different topics taught in school**, but provides little detail or context (ex: I used science).
- The student vaguely describes how the interdisciplinary knowledge learned through the program connects to **daily life**.

3=Developing:

- The student vaguely describes connections between different subject matter, and applies some knowledge from one discipline to another with some description on how the knowledge relates.
- The student describes **connections between different subject processes** with some description on how the knowledge relates.
- The student describes a **connection between** the knowledge learned through participation in "Sciencing Out" and **different topics taught in school** by providing vague details and context (ex: I used math to solve a science problem).
- The student describes how the interdisciplinary knowledge learned through the program connects to **daily life**, but neglects to explain why they connect.

4=Accomplished:

- The student clearly describes **connections between different subject matter**, and explains in detail how they applied knowledge from one discipline to another.
- The student describes **connections between different subject processes**, and explains in detail how they combined processes.
- The student clearly describes a **connection between** the knowledge learned through participation in "Sciencing Out" and **different subjects taught in school** by providing thorough descriptions, which include detail and context.
- The student clearly describes how the interdisciplinary knowledge learned through the program connects to **daily life** by providing robust descriptions of the connection.

Measuring student understanding of STEM/STEAM topics	1	2	3	4
Connects different subject matter: Example: The student discusses a connection				
between human anatomy and primate anatomy. But if the student had				
compared different types of primate anatomy, it would not count as connecting				
different subject matter.				
Combines different processes (ex: creative and scientific process): A process is				
the different steps that a scientist/engineer/artist/mathematician uses to arrive at				
a goal. The student combines different processes to reach a conclusion. Example:				
A student creates sketches to make scientific observations of a subject. A student				
builds/engineers a device to collect scientific data. The student has clearly made				
use of the arts (video skills) to explain the scientific process of data collection.				

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Connects program experience to interdisciplinary learning in school:

Example: The student makes direct connections to subjects taught in school by explicitly stating something like, "we learned about this in school, but while observing it in the wild, we learned more about it."

Connects the interdisciplinary knowledge learned to daily life: The student explains how this knowledge connects to daily life and describes why it is important to know and care about this knowledge. Example: If a student says something like, "we should protect the forest," include this here and rate it based on if they described why and how it connects to daily life.

A5. Facilitator & Scientist Evaluations:

The purpose of this research is to examine the student impacts of immersive STEM/STEAM (Science, Technology, Engineering, Art, and Engineering) education programs. This research is being conducted as part of the graduate degree program of Susan Dorsey and the Principal Investigator of "Sciencing Out", Tsiory Andrianavalona, PhD. Only the researcher, principal investigator, and faculty advisor will have access to individual responses and results of the survey will only be presented publicly as aggregate summaries.

Rate the importance you place on each of the following possible student experiences through Sciencing Out using the 7-point scale:

(1) No importance, (2) Low importance, (3) Slightly important, (4) Neutral, (5) Important, (6) High importance, (7)Extremely important

Students have a hands-on, awe-inspiring experience that sparks curiosity during their participation in "Sciencing Out".

Students think critically during facilitated programming through "Sciencing Out".

Students connect with science techniques and learn how science can teach about the present and past.

Students develop knowledge/skills during the "Sciencing Out" experience related to school curriculum.

Students learn from experts about STEM topics.

Raise interest in STEM careers among students through "Sciencing Out".

Foster a connection between students and Madagascar's unique biodiversity.

Students are empowered to share their experiences with Madagascar's unique wildlife within their communities.

How likely are you to recommend this program to your peers?

(1)I will not recommend, (2)I may recommend, (3)Neutral, (4)I will recommend, (5)I will highly recommend

Please explain your response below:

Free-Response Questions:



How many years of experience do you have educating high school students with in-field experiences involving STEM learning? Describe your experience. Do you think "Sciencing Out" was impactful for students? Why or why not?

Do you think "Sciencing Out" was impactful for students? Why or why not?

What did you enjoy most about working alongside students?

What did you find challenging about working alongside students?

Is there value in STEM education outside of the classroom? Why or why not?

What did you enjoy the most about facilitating the "Sciencing Out" program with students?



Table B1
Facilitator & Scientist Post-Program Evaluation Responses

			Strongly Disagree						Strongly Agree
Facilitator & Scientist Questions	Mean	SD	1	2	3	4	5	6	7
	Post	Post	Post	Post	Post	Post	Post	Post	Post
Q1: Students have a hands- on, awe-inspiring experience that sparks curiosity during their participation in SciOut.	6.8	.38	-	-	-	-	-	16%	83%
Q2: Students think critically during facilitated programing through SciOut.	6.3	.65	-	-	-	-	8%	50%	41%
Q3: Students connect with science techniques and learn how science can teach about the present and past.	6.25	.75	-	-	-	-	16%	1%	41%
Q4: Students develop knowledge/skills during the SciOut experience related to school curriculum.	6.1	.93	-	-	-	-	33%	16%	50%
Q5: Students learn from experts about STEM topics.	6.25	.62	-	-	-	-	8%	58%	33%
Q6: Raise interest in STEM careers among students through SciOut.	6.25	.62	-	-	-	-	41%	58%	33%
Q7: Foster a connection between students and Madagascar's unique biodiversity.	6.75	.62	-	-	-	-	8%	8%	83%
Q8: Students are empowered to share about their experiences with Madagascar's unique wildlife within their communities.	6.9	.28	-	-	-	-	-	8%	91%

			I will	I	Neutral	I	I will
			not	may		will	highly
Facilitator & Scientist Questions	Mean	SD	1	2	3	4	5
	Post	Post	Post	Post	Post	Post	Post
Q9: How likely are you to recommend this program to your peers.	4.91	.28	-	-	-	8%	91%

 $Note.\ Mean,\ STDV,\ and\ Percentage\ Response\ Scores\ For\ SciOut1\&2\ Facilitator\ Post-Program\ Evaluation\ Questions\ On\ A\ 7-Point\ Likert\ Scale.$



RESEARCH REPORT

"We didn't know we were doing science": Engaging with science and mathematics in an afterschool program

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Abstract

An extensive number of empirical research studies support the engagement of young children and youth in out-of-school science, technology, engineering, and/or mathematics learning experiences. In this case study, we add to this knowledge base through examining how rural middle school learners engage with science and math concepts and practices through an afterschool program that emphasized the development of STEM content, skills, and practices using the field of archaeology, as well as Indigenous knowledges, as mediums. Results highlighted how various syncretic approaches within the afterschool program afforded 61 middle school aged learners' opportunities to engage with math and science concepts common to archaeologists and Indigenous peoples. We illustrate this through five "doings." For example, learners engaged in similar science practices to Indigenous peoples through considering how local landscapes and the natural environment informed decisions regarding settlements. This study concludes with recommendations for professional archaeologists and educators to adapt and/or develop a similar afterschool program to support students' participation as ARCH + STEM learners.

Keywords: Archaeology, Afterschool Program, Middle School, Syncretic Approach

To cite this article: Simpson, A., Miroff, L. E., Carroll, L., Versaggi, N. M., McCann, J., Murtaugh, D., & Coles, J. (2023). We didn't know we were doing science": Engaging with science and mathematics in an afterschool program. *Journal of Research in STEM Education*, 9(2), 78-102. https://doi.org/10.51355/jstem.2023.135.

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A substantial amount of prior research has documented how participating in science, technology, engineering, and/or mathematics (STEM) experiences in informal learning environments² has the potential to shape youths' developing identity and self-confidence in STEM (Allen et al., 2019; Young et al., 2019), positively improve youths' perception of STEM careers (Tyler-Wood et al., 2012; Vela et al., 2020), enhance and extend learning of STEM concepts (Duran et al., 2014; Roberts et al., 2018), increase enrollment in advanced STEM courses (Young & Young, 2018), foster problem-solving skills (Allen et al., 2019), and develop and sustain youths' interest in a STEM field (Allen et al., 2019; Soto-Lara et al., 2021). Moreover, such experiences at an early age have been shown to be predictive of post-secondary learners' STEM identity, competence and engagement in science and mathematics (e.g., Dou et al., 2019; Goff et al., 2020; Rodriquez et al., 2019). The majority of research examining youths' participation and growth as STEM learners in informal learning environments is situated within programs and experiences framed within STEM fields such as robotics and game design (Newton et al., 2020), information technology (Duran et al., 2014), and environmental science (Ballard et al., 2017).

In this study, we focused on a novel afterschool program geared towards the development of middle school learners' STEM content, skills, and practices using the field of archaeology and Indigenous knowledges as mediums. To date, there is limited research that provides and examines ARCH+STEM opportunities for youth. Limited prior research highlights the possibility to engage learners in STEM practices and processes through archaeological concepts and Indigenous material culture (e.g., Beatty & Blair, 2015; Ducady et al., 2016; Moe et al., 2016). For example, as part of an archaeology program, students were observed engaging in the practices of observation, using data or evidence to answer a question, developing hypotheses, stating and supporting conclusions, and making inferences based on observations and/or evidence (Ducady et al., 2016; Moe et al., 2016). These are science practices that align with the practices identified by the National Science Teaching Association (2014) as appropriate for students in grades K-12 in the U.S. These science practices are grounded in behaviors and actions that scientists employ as they investigate scientific phenomena. In addition, students have been found to engage in mathematics practices and reasoning while participating in archaeological and Indigenous activities and curriculum (Beatty & Blair, 2015; Ducady et al., 2016). As argued by Beatty and Blair (2015), these opportunities to participate in and connect with Indigenous ways of knowing afforded learners the opportunity to reconceptualize what it means to do math through a humanistic approach, the art of looming beads. For example, students worked with patterns on three levels: (a) the overall pattern, (b) the relationship between columns, and (c) the relationship of the bead within a column.

ISSN: 2149-8504 (online)

² The informal learning environment in this study is defined as a voluntary setting with an instructional focus and guidance for learners, does not involve external assessments, embedded in meaningful activity, and includes innovation of new and current knowledge and skills (Rogoff et al., 2016).



In addition, we refer to this program as ARCH+STEM to highlight the integrated nature of STEM, archaeology, and Indigenous knowledges. The history of North American archaeology includes a long record of colonialism expressed as exploitation of archaeological sites for research and teaching, amplified by a disregard for the knowledge of Indigenous peoples (Cowell, 2017; Witt & Hartley, 2020). Today, most archaeologists acknowledge that Indigenous people and their traditional knowledge play critical roles in the process of interpretation and education, fueling a new era of decolonizing the field of archaeology (Atalay, 2012). As part of the afterschool program, educators aimed to provide a place for Indigenous people and traditional knowledge to inform the learning and doing of STEM concepts through integrating Indigenous voices and worldviews (Snively &Williams, 2018). More specifically, educators worked closely with individuals from a Haudenosaunee Nation to make connections to learners' local region, but also because not including their voices and perspectives would continue colonialism through archaeological practices.

Therefore, this study will add to our current knowledge base of STEM-related informal learning environments by answering the following research question: How do middle school aged learners engage with science and mathematics concepts and principles within an afterschool program grounded in archaeology and Indigenous knowledges? In this study, being engaged is characterized as involvement in an activity, in particular being involved in an activity that encourages the application and enactment of science and math concepts and principles. This is not to be confused with engagement, which has been defined as the "intensity and emotional quality of students' involvement" (Pugh et al., 2010, p. 3). Our intent is not to examine learners' level of participation but understand how the afterschool program afforded youth opportunities to "do" math and science through archaeological ideas and concepts. These "doings" are often hidden or implicit within youths' practices as science and math learners (e.g., Lancy, 2012; Simpson et al., 2020), and involve active as opposed to passive participation as learners (Forbes & Skamp, 2019; Zhai et al., 2014). Prior research has highlighted how doing math and science has positive influences on children's perspectives and beliefs of science and math as a field and as a career (e.g., Hacioglu & Gulhan, 2021; Kwon et al., 2021; Vennix et al., 2018). For instance, Forbes and Skamp (2019) noted how Grade 5-6 students' "doing science" shifted their understanding of science as an active human endeavor that includes hands-on collaborative projects. However, students typically have narrow views regarding what constitutes science and mathematics outside of the classroom context as school expectations and ways of operating are in discord with other programs and learning institutions (Archer et al., 2010; Masingila et al., 2011; Narayan et al., 2013; Pattison et al., 2016). For example, Grade 4 students in Singapore drew images that indicated doing science as (a) hands-on investigations, (b) learning from the teacher, (c) completing the workbook, and (d) a social process and not an individual process (Zhai et al., 2014).



As such, this study addresses Penuel's (2016) call for more research on STEM in practice, particularly through supporting learners to find new ways to relate and understand their world, as well as the call by Colaninno (2019) for STEM discipline-based education research in archaeology. Through the results of this study, we make an argument for archaeology and Indigenous perspectives in supporting middle school students' "doing" science and mathematics. We contend that the significance of this study lies in the potential for professional archaeologists and educators in other communities to develop a similar afterschool program to support youths' engagement as STEM learners. This may have long-term implications for who chooses to obtain a degree and career in a STEM field, fields that historically exclude particular social identity groups such as women, persons with disabilities, Indigenous people, as well as individuals who identify as Black or African American or as Hispanic or Latino (NSF, 2023; Ruef et al., 2019). As described by Lancy (2012) and Rahm and Ash (2008), experiences in informal STEM programs, such as the ARCH+STEM program, are part of an accumulation of STEM experiences that will support an individual's development and transformation through experiencing an insider status.

Theoretical Grounding

The afterschool program and research study were guided by humanistic approaches to math and science concepts and processes (e.g., Aikenhead, 2021; Goffney et al., 2018; Simpson & Kastberg, 2022). This is understood in this study "as a human activity, a social phenomenon, part of human culture, historically evolved, and intelligible only in a social context" (Hersh, 1997, as quoted by Skovsmose, 2012, p. 379). As an example, when asked "how far is it to the [Fitzroy] river," 56 Indigenous students responded using a non-standard length of measurement – time it would take to walk to the river (Grootenboer & Sullivan, 2013). Students' responses were social and cultural in nature (Jin, 2021; Owens & Kaleva, 2007), as well as grounded in their experiences and cultural understanding of mathematics (i.e., human sense-making; Aikenhead, 2021). Broadly speaking, integrating this theoretical grounding within the afterschool program plays a role in aiding middle school students in learning "from our more-than-human relatives" through relational understandings of knowing of the local land (Gutiérrez, 2020, p. 380). In this study, humanistic approaches to math and science concepts and processes lied within the intersection of ARCH + STEM as learners are engaged in human activities unique to the field of archaeology, as well as Indigenous perspectives of STEM focused on relationships and being with nature (Garcia-Olp et al., 2020). Such humanistic approaches to engaging learners in STEM are often missing from school contexts (e.g., Duchscherer et al., 2019; Simpson & Kastberg, 2022) and through an informal content lens (Rahm, .2021).



In addition, we drew insight from Vygotsky's (1986) and Saxe et al. (2015) notion of bringing together two forms of cognitive development – scientific concepts and everyday or spontaneous concepts – as there is a possibility for both forms of development to be in interplay with one another (Simpson et al., 2023). Gutiérrez and Jurow (2016) described this as "grow[ing] into each other" (p. 575) as every day and scientific concepts inform and shape one another as opposed to privileging one over another. This is similar to Moje et al. (2004) third space described as the integration of competing and/or alternative spaces, each with their own rules and norms for how to behave and act (e.g., ways of talking). In this study, our interest was not only in engaging students as participants within the intersectionality of everyday knowledges and scientific knowledges in the field of archaeology, but between Western and Indigenous understandings of science and mathematics (Brayboy & Castagno, 2008).

Methods

For this study, we employed a single instrumental case study (Stake, 1995). An instrumental case study afforded researchers the possibility to investigate STEM participation among rural middle school students within an archaeological afterschool program. The afterschool program is "atypical" as little to no published scholarship exists on the extent of supporting the participation of youth as STEM learners through an archaeology afterschool experience. Archaeology has been used in formal learning situations (e.g., Dulnuan & Ledesma, 2020; Popson & Selig, 2019) and other types of informal learning situations and contexts such as simulations, television/media, museums, and field experiences (Rockman, 2003; Thistle, 2012; Watters, 2015).

Program Description

The afterschool program was designed for middle school learners to gain knowledge of and participate in the STEM disciplines as taught through archaeological concepts and Indigenous knowledge of science, particularly Indigenous people's respect for the environment and all its ecological components. In general, modules were initially designed for a summer program and were more fully developed for the afterschool program to bring STEM concepts to the fore. For instance, participants in the summer programs have thrown darts with an atlatl for years, but there was little discussion about the physics behind its use. In the afterschool program, the atlatl was used to discuss levers and force. As another example, one module focused on how archaeologists use the Pythagorean Theorem to construct a 1-meter by 1-meter excavation unit. Students were challenged to employ any strategy to create the perfect square before discussing how the theorem was used to set up an excavation unit. Next, students were provided an opportunity to apply the theorem in their construction of a perfectly square excavation unit.



The program spanned a 10-week period. The focus was on the precontact history of the Northeastern region of the United States because of the ability to make connections to middle school learner's experiences (e.g., fishing and hunting) and local environments (e.g., rivers and archaeological sites). As an example, learners were introduced to how precontact Indigenous people viewed environmental variables to help them form sustainable communities on the landscape. Learners explored the landforms around their school through examining topographic maps and walking around their school grounds. See https://archaeolessons.com/ for a list of topics and plans implemented in the afterschool program.

Context

The data for this study is from three public middle school sites located in rural areas within the same county in New York State. In spring 2021 and fall 2021, the afterschool program took place in Windy School District³. The school served approximately 1,528 children living within a 110-square mile radius. The student population across all grade levels was majority White (91%) with 52% identified as economically disadvantaged and a graduation rate of 92% (New York State Education Department [NYSED], 2022). In fall 2021, spring 2022 and fall 2022, the afterschool program was also implemented in Wiley Point School District, which served about 1,329 children living within a 114-square mile radius. The student population was majority White (96%) with 58% identified as economically disadvantaged and a graduation rate of 78% (NYSED, 2022). Lastly, in spring 2022, we worked with Happy Valley School District. This district served about 601 children living within a 91-square mile radius. The student population was majority White (95%) with 6% identified as economically disadvantaged and a graduation rate of 87% (NYSED, 2022). See Table 2 for an overview of the program at each school site.

Table 2. *Site overview*

Semester	School	Day(s) of the Week	Length of Time per Day	# of Learners
Spring 2021	Windy	Tuesday, Thursday	1.5 hours	16
Fall 2021	Windy	Tuesday, Thursday	1 hour	15
Fall 2021	Wiley Point	Wednesday	2 hours	26
Spring 2022	Wiley Point	Wednesday	2 hours	8
Spring 2022	Happy Valley	Thursday	2 hours	24
Fall 2022	Wiley Point	Thursday	2 hours	12

³ Names of the schools are pseudonyms.

ISSN: 2149-8504 (online)



Each school site offered an afterschool snack and late bus transportation for all students, which afforded middle school learners access to the program by eliminating issues of access that are often associated with afterschool programs in geographically rural areas (Collins et al., 2008).

Participants

We recruited our participants in collaboration with the three middle schools as information about the program was sent electronically and/or physically to every parent and guardian of learners in Grades 6-8. Over the three semesters, approximately 101 learners across the three sites participated in the afterschool program with 61 providing consent and assent to be a part of the research study. Of the 61 youths participating in the research, 40 (\sim 66%) were in 6th grade, 11 (\sim 18%) in 7th grade, and 10 (\sim 16%) in 8th grade. In addition, three participants (\sim 5%) self-identified as non-binary, one (\sim 2%) as trans male, 28 (\sim 46%) as female, and 24 (\sim 39%) as male. Four participants preferred not to self-identify their gender (\sim 7%) and one noted "still figuring that out." Lastly, the majority of our participants self-identified as White (n = 49, 80%). Six (\sim 10%) participants self-identified as Two or More Races, two (\sim 3%) identified as Asian, and two (\sim 3%) identified as Black. Two preferred not to self-identify their race.

Data Source and Analysis

Field Notes

The main data source for this study was field notes documented by one member of the research team. Field notes were documented approximately once a week during the spring 2021 and fall 2021 programs at Windy Middle School and every Wednesday or Thursday during the programs at Wiley Point Middle School and Happy Valley Middle School. Prior to collecting field notes, we watched a video clip from another research study in which upper elementary aged students worked together to code a robot to traverse a taped path from one side of the room to another. We did not have access to a program or similar data within an archaeological context. The purpose of this was for several reasons. One, to practice documenting verbal and non-verbal acts of communications. Two, to discuss what we observed in terms of students' doing math and science (e.g., practices, skills, and processes). Three, to reflect upon our prior experiences and subjectivities as STEM learners, educators, and/or researchers, and how these informed our observations (e.g., McDonald et al., 2019).

As passive observers, we walked around the periphery of the classroom during whole-group discussions. During small group interactions, we would spend between 5 and 7 minutes at each group before rotating to another group. Within 24 hours of the observations, the written field notes were translated into a two-column document (Stake, 1995). In the left-hand column were the field notes. Field notes documented the verbal and non-verbal ways in which youth engaged in math and science concepts and principles in the program. This included their



interactions with one another during small group activities, interactions with educators, and whole-group discussions. These were expanded upon and detail was added to "complete" what we were not able to document in our notes at the time of data collection. The right-hand column included our interpretations as to how learners were engaged in the activity. See Figure 1 for a two-column example from the Hypothesis Testing module. Within this module, groups of learners were given wrapped boxes in which they had to form a hypothesis about what was inside through using their senses to gather evidence (Science Museum Group, n.d.). The example below is from the second half of the activity in which groups of students justified and supported their hypothesis with evidence. Researchers met each week to discuss the observations in terms of how the middle school students engaged in science and math concepts through archaeological concepts and Indigenous ways of viewing science and math.

Observations	Interpretations
Box #1: (a) tiny pebbles because it was light and could hear dust coming off, (b) LEGOs because it felt small, (c) shell because it felt light and could hear something else in there, and (d) paper clip because it would slide and not roll. Box #2: (a) arrowhead because it felt flat, (b) marbles because it rolled around, (c) LEGOs because it was loud, and (d) action figure because it seemed like a rectangle and sounded like plastic (how it hit the box) Box #6: (a) rocks, (b) LEGOs because not round and small, (c) beads because there were multiple and plastic, and (d) m-&-m's or skittles because tiny items that rattled, but had a different sound from other boxes.	Students were providing evidence to support their guess; thus, continuing their participation within a scientific process and as a scientist. Educator continually probed with "What is your evidence?" Communicating "results" is also a practice engaged with in science. It is interesting to see how some of their evidence is so "off the wall" like smelling dirt. "Good" science practice to warrant claims without substantial evidence?? I also think there is something to thinking about what it cannot be.

Figure 1.Two-column example of field notes

Next, we looked across field notes to consider similarities or patterns in our observations and interpretations. For example, Figure 1 highlights how students were communicating and justifying their hypotheses around what was inside each mystery box through providing evidential claims based on observations. This was communicated through a class discussion. We found other activities that supported this observation. For example, groups of students were observed communicating and defending how they sorted and characterized projectile points to their peers. As such, our focus was not on examining math and science concepts as privileged by state standards but considering how students engaged with science and math concepts and



principles through authentic and humanistic approaches (e.g., Moschkovich, 2002; Philip & Azevedo, 2017) common to archaeologists and through Indigenous perspectives.

Focus Group Interviews

Focus group interviews were conducted to promote dialogue regarding participants' lived experiences and interpretations of their participation in the program (Kamberelis & Dimitriadis, 2013). We expected focus groups to promote a kind of "memory synergy" among participants (Kamberelis & Dimitriadis, 2013, p. 40). We further supplemented this with showing them pictures or a list of the various activities in which they engaged throughout the program. Focus group interviews occurred at the conclusion of each 10-week program. We developed the interview questions as a research team. Example questions from the semi-structured protocol included (a) Were there any activities that you can remember using or engaging with math? Tell me more; and (b) Were there any days or activities that you can remember using or engaging with science concepts? Give me an example. The interviews lasted approximately 30 minutes and were conducted in-person by the first author in a classroom at the school. All focus group interviews were audio-recorded and professionally transcribed. Transcripts were reviewed for accuracy and edits were made when necessary.

For this study, the focus group interview data was not analyzed but served as a form of triangulation, a validity procedure to corroborate evidence of the field notes across the different semesters and school sites (Denzin, 1984). Quotes in which students talked about how they engaged with math and science within the various modules were pulled out and compiled by module. We integrated a few quotes within the results to highlight how learners engaged with science and mathematics concepts and principles within the afterschool program. Participant developed pseudonyms are used to refer to learners.

Results

We begin the results with a quote from Timothy (8th grade); "I feel like it kinda changed me 'cause it opened me up to more things. We have a PLTW [Project Lead the Way] program that we use STEM. And I feel like this one kinda opened me a lot more to the archaeology point of STEM." While we cannot claim this to be a similar experience to other participants, this quote highlights how the program was an extension of STEM concepts and practices at his school. In addressing how students engaged with science and mathematics through the various modules within the archaeology afterschool program, we found five "doings" – (a) engaging with math concepts as archaeologists, (b) engaging with science concepts as Indigenous peoples, (c) engaging in math concepts as Indigenous people, (d) engaging in observational skills as archaeologists, and (e) engaging in a scientific process as an archaeologist.

Doing Math Concepts as Archaeologists

Excavation Sites

The standard archaeological excavation unit is a regular square unit, often with each of the four sides measuring exactly one meter. This aids archaeologists in documenting the location of objects recovered within a relatively small area (i.e., 1m^2 unit). Working in teams of 2-3, learners were first challenged to create a one-meter by one-meter perfect square using four nails and a tape measure (see Figure 2-A).





Figure 2-A

Figure 2-B

Figure 2. Images of learners constructing a 1m² excavation unit

Students were able to place three nails to form two congruent sides of a square, each side measuring 1-meter in length. This is represented in Figure 3. Next, youth used their tape measure to find the distance of 1-meter from Stake 1 (S1) or S3. This is where they would place the fourth stake. When measuring each of the sides again, they determined that not all sides of the square were 1-meter in length. Therefore, placement of the fourth stake involved the mathematics practice of productive struggle as they continued to measure and reposition the stakes in search of a perfect square or excavation unit. As stated by Ezerelda (8th grade), "It was a little bit frustrating because you'd have to like, keep putting it in and, like, keep trying to make it even."

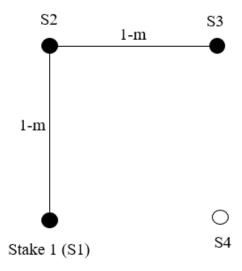


Figure 3. Diagram of creating a perfect square using trial and error

After approximately 15-minutes, students were presented with the Pythagorean Theorem, which states that the square of the length of the hypotenuse of a right triangle is equal to the sum of the squares of the lengths of the other sides or the legs (i.e., $a^2 + b^2 = c^2$). Collectively, the middle school participants found the hypotenuse to be approximately 1.41 meters in length. This theorem is often utilized by archaeologists when laying out excavation units because it produces a more precise square. As illustrated in Figure 2-B, one learner held the end of a tape measure with a length of 1-meter at one stake, while an educator held the end of another tape measure measuring about 1.41 meters at another stake. Another learner joined the two tape measures at a point where the two tape measures crossed. This is where a third stake was placed. This process was repeated to place the fourth stake. Tyra (6th grade) described this as "Yeah, so you had to go this way [formed diagonal across body with right arm]. This way [formed diagonal across body with left arm]. This way [both arms vertical], and this way [both arms horizontal]."

Lastly, this activity engaged students in utilizing a meter as the unit of measurement. This was novel as learners in the U.S are not often introduced to the metric system, but the Imperial system (e.g., feet). As we observed, learners were somewhat confused by this unit of length. For example, asking "what is a meter?" Or "how many centimeters is a meter?" Hence, middle school participants engaged in using a form of measurement more common to the practices of archaeologists than supported in their school experiences. We have evidence from one focus group interview in which a meter was discussed within this activity, and only this activity. As stated by Kit-Kat (7th grade), "They [archaeologists] used certain measurements for like certain things." Greg (7th grade) elaborated upon this as he noted how archaeologists "used one meter by one meter, I think, sized cubes of area of work."

Orienteering

In this module, learners explored how to navigate their surroundings with a compass, which is a tool archaeologists use to make maps of a project or site and to navigate the landscape in order to locate geographic features or sites when doing fieldwork. After exploring how a compass worked (e.g., hold flat in hand and in front of your stomach), learners used spatial reasoning skills as they oriented and positioned their bodies in the direction of north or when moving their bodies 160 degrees using the compass as a guide. Three groups of learners then used this skill to lay out a straight line due 180 degrees south and measured 30 meters in length. They placed a pin flag every 4 meters (see Figure 4-A). This simulated an archaeologist marking locations where they would systematically excavate across a landform to look for cultural material. Throughout this activity, learners were observed using their compass to ensure that their line was straight or 180 degrees south (i.e., spatial reasoning; see Figure 4-B). When asked how he knew he was consistently heading in the appropriate direction, Eastern (6th grade) stated "the red arrow is pointing at him."





Figure 4-A Figure 4-B

Figure 4. Use of the compass to ensure laying a straight line

At the end of this activity, the three lines of pin flags should be parallel to on another. We observed an interaction between an educator and a sixth-grade student, Lion, regarding this. "Do you think it looks parallel? How can we test?" Lion pointed from one flag in one line to another flag in another line, but did not articulate anything verbally. When probed further, Lion stated "they never touch." This alone did not imply that the lines in this activity were parallel lines. The educator followed by asking, "but how do you know?" Lion eventually indicated measuring the distance between two lines from start to end and the distance should be the same. Lion also



seemed to have another idea as he added "or make sure each flag is 180 degrees south," which could be an appropriate approach based on the learners' body position.

The last part of this activity engaged students in counting the number of paces to walk 15 meters. They were then asked to calculate the number of steps they would walk if they needed to find 10 meters. As explained, sometimes it is not possible to use a tape measure to measure how far archaeologists are walking. In such cases, knowing their pace helps them measure how far they walked without using a tape measure every time. We observed students engage in different approaches to solving this. Ken (6th grade), for example, began by dividing his pace of 17 by three as he was then going to double this amount to find his pace for 10 meters. While thinking of this appropriately, the division was difficult for Ken. Koko, on the other hand, inappropriately added her pace of 15 steps, ten times to equal 150 steps. In an interview, Iguana (6th grade) chose logician/mathematician as one of their identities as they recalled "doing those weird wide lines and using math to figure how much each of my steps were."

Doing science concepts as an archaeologist: Faunal Analysis

The goal of this activity was for learners to participate in the process of faunal analysis as they identified animal bone types and the animal to which the bone belonged (e.g., cow, pig, deer). In our field notes, we noted how middle school participants were asked questions that encouraged observation (e.g., "What do you notice? Does that look like anything on the table?"), exploration (e.g., "Keep looking. Don't give up."), and comparing and contrasting their bones to those from a collection (e.g., "How is it similar or different to the bone in your hand?"). Learners were observed considering the texture of the bones, putting bones together for fit, and discussing the color of the bones (see Figure 5). These practices of observing, exploring, and comparing are foundational ways of engaging with science as an archaeologist. In the interviews, learners also highlighted the practices of observation and exploration. For example, Zorea (8th grade) stated, "We were looking at the bones and matching certain parts of the parts, even though I got a bit frustrated once or twice. Like, I got a piece that looked like an adult and had like very smooth edges. But then it's not like an adult. So, it's like, is this a teenager? Or is it the size of a baby, but more have adult features? Is this even the right animal at this point?"









Figure 5. Participating as a faunal analyst

Doing math concepts as Indigenous peoples

Stone Tools/Flintknapping

Flintknapping is also a process that engaged STEM learners in applying various concepts, namely, geology, physics, and mathematics concepts. Flintknapping is the making of stone tools from lithic raw materials such as chert, jasper, and obsidian. Only stones with particular attributes can be used to make tools (e.g., brittle, no internal fracture planes, elastic, etc.). The manner in which the material breaks can then be determined by the knapper and their application of force. In our field notes, we documented students being presented with different types of stones found in the local area and asked to consider the properties to look for in stones that could be used for flintknapping. Responses from students included "rocks that are thinner" and "break in certain ways." Eventually, students were provided with an opportunity to participate in the process of flintknapping. This process required students to hit the edge of the raw material with a hammerstone or an antler billet at an angle less than 90° (see Figure 6-A). The energy passes through the material in the shape of a cone, allowing a flake to be removed. As stated by an educator, "It's gotta be less than 90 degrees. The closer to 90 degrees, the larger the chunk." This process was also grounded in physics concepts as the hammerstone transferred energy when hitting the stone. Once students had a flake, they participated in the tool making process, which required youth to use an antler tine to remove smaller flakes (pressure flake) and shape it into a tool like a projectile point (see Figure 6-B). This task requires the same knowledge about the raw material and angles to remove flakes of a certain size and from particular areas of the larger piece. Students often used their flakes to cut different materials such as leather and tree branches. In one observation, North and Octonaut (6th grade) struggled to cut through leather, stating, "This tool isn't super sharp."









Figure 6-A

Figure 6-B

Figure 6. Students participating in flintknapping and tool making

In our observation, some students may or may not have been aware of how to apply these concepts when producing flakes. We heard educators providing guidance such as "how about we turn it because remember we are looking for that angle" and "…look at how you are holding it. We want to hold it at a tilt so we can chip away a piece of flake and not explode the material." On the other hand, when asked why he tried to hit a rock at a certain angle, North stated, "I decide the angle based off of where the energy should be placed to cut through the rock." Another student, Jimeboop (6th grade) added, "If you hold the antler up further it provides less force when you hit the rock and if you hold it closer to the base, it creates more force."

Doing science concepts as Indigenous peoples:

Atlatl

An atlatl, or spear thrower, is a stick or short pole in which the end of a dart is inserted into a wood or bone hook (see Figure 7). The use of an atlatl allows for the dart to be thrown farther and with more force than if thrown only by hand. Learners were first introduced to the physics behind throwing a dart with an atlatl. We documented phrases such as "potentially increase the amount of force/distance," "...by pulling back, it builds up force," "your arm serves as a lever and fulcrum with a pivot point," and "each one builds up additional force." As such, the atlatl serves as an extension of an individual's arm and acts as a lever when thrown. For instance, the extension of the forearm (i.e., forward throwing motion) uses the elbow as the pivot point or the fulcrum. The flick of the wrist at the end of the throwing motion also serves as a lever system. The triceps produce the force to throw a dart with an atlatl with very little motion. As depicted in Figure 7, youth engaged in throwing darts using an atlatl; therefore, applying the physics concepts as STEM learners in the program, as well as mirroring the actions of Indigenous people.

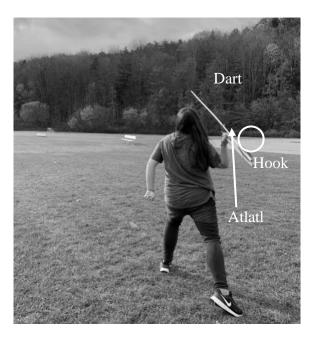


Figure 7. Image of using an atlatl

Further, as noted in observations, students also chose to throw their darts differently to determine the best method – turning torso to throw, standing still and only moving arm/wrist, and running prior to throwing – as well as where to hold the atlatl – closer to the front or closer to the back. Therefore, some students informally engaged in a science process of experimenting with different variables, observing and collecting data, and interpreting their results. Following the action of throwing with the atlatl, we also noted students being able to discuss how different variables impacted how far they threw a dart. For example, one student noted how the different characteristics of the three atlatls used seemed to have impacted how they threw the dart. Arm position and the release point were other variables discussed. This highlighted learners' engagement with science as they considered how different factors may influence the results of how far a dart is thrown.

In the interviews, middle school participants often related science to this activity. On a rudimentary level, Ezerelda (8th grade) noted science was involved in "how you throw the atlatl." Students were able to describe factors that may or may not have affected how far the dart was thrown. The following example from two 6th graders, Tyra and Eve, highlights how the strength of an individual and an individual's throwing style were two factors considered. Tyra noted, "You don't have to be really strong to be able to do it. You just need force." Eve added, "Yeah, and certain ways you throw it can affect how far it goes or how high. And if you let it go down here, it's going to hit the ground." In addition, students used language grounded in the physics concepts introduced by educators (e.g., levers, force). As one example from a focus group, Casey (8th grade) stated, "…like the levers, and then the force. And I know force is like a Newton thing."



Greg built upon this, "You use your arm as a lever and the atlatl as a lever to make the spear go farther." However, this was also an activity in which students expressed the "hidden" nature of science within their actions This was expressed well in the following comment by Kitkat: "I think the atlatls because when we were doing them, we didn't really think about science, we were just like having fun, just throwing them. We weren't really thinking about the science behind it. After a few tries, I realized that I put force on it, and that's when I realized that was like science."

Landscapes

In this module, learners considered how Indigenous people determined what landscapes (i.e.., floodplains, terraces, and uplands) were best for habitation sites, and which areas were best for specific land use activities, such as fishing, plant collecting, and hunting. Learners explored these ideas through landscapes around their school. For example, learners at Windy Middle School were given a scenario that positioned them to think as people who lived hundreds or thousands of years ago. "Consider if that hill was covered with snow. As a south facing hill, what happens when the sun comes out? The snow will melt, which means the animals will come out and eat nibbly things. Was this a good place for people to live?" A few students responded with yes. Elliot (8th grade) added that this would only be ideal temporarily as living near a river might be ideal in summer months. As another example, learners at Happy Valley explored areas near a river that flowed by their school (i.e., floodplain). As asked by an educator, "would this be a good place to have your village?" Students responded with no because there was a high chance of flooding. "Where would be a good place for the village?" Learners discussed across the river where there was a higher elevation. "What might you do right here [on the floodplain]?" One student shouted out fishing, but not gardening. They further inquired about being able to make pottery due to the amounts of clay. As these examples highlight, learners were gaining an understanding of how the various landscapes and the natural environment informed decisions regarding settlements of Indigenous peoples.

Doing a Scientific Process: Research Projects

Near the end of the program, learners had the opportunity to engage with science and mathematics, as well as professional archaeologists, as they worked in groups to define and implement their own research study. This study was based on an archaeological topic of interest to them, specifically a topic grounded in their prior participation in the program. To illustrate, we present the research project of three learners – Leonardo, Timothy, and Poly. Through the program, they learned how Indigenous people used raw materials like bone, wood, and stone/flake for different functions. The purpose of their study was to determine which raw materials scraped, cut, and drilled the best (see Figure 8-A). They hypothesized that the flake would cut, scrape, and drill the best. The experiment included scraping, cutting, and drilling a carrot five times using the three different tools (see Figure 8-B). As a specific example from their



poster, "we took the three tools and used a cutting motion on a carrot five times. Then we measured how deep the cuts went into the carrot." They concluded that their hypothesis was incorrect as the results highlighted a flake was best for scraping, wood for cutting, and bone for drilling.



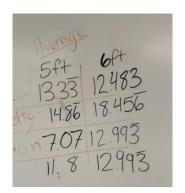


Figure 8-A

Figure 8-B

Figure 8. Image of raw materials and cutting motion

Next, learners created a poster based on their research. As described by one of the educators of the afterschool program, "All scientists have to present their research, but it is not helpful if we are only speaking with one another in the research field. Research should also be presented to the public. One way to do this is posters." Field notes confirmed learners' "doing" research similar to the professional practice of STEM professionals as their posters included an abstract, an objective, materials, methods, results, conclusions, and references, if applicable. Learners engaged as a collaborative team of scientists in creating their posters. One new skill a majority of the learners gained was how to create graphs in Google Sheets. As an example, one group calculated the average throws per person based on their hypothesis that a short dart would be thrown further than a long dart when thrown with an atlatl (see Figure 9).



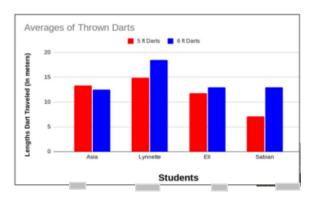


Figure 9. Results presented as averages in a table and a bar graph created in Google Sheets

ISSN: 2149-8504 (online)



Lastly, learners presented and communicated their research through an archaeological perspective to the public (e.g., teachers, parents, administrators) by participating in a poster session at their school. The posters served as a visual modality and were written to be understandable to a range of individuals. In our observations, we often described how the research projects provided students with hands-on explorations (i.e., learning through doing), as well as engaging them in "hidden" science and mathematics practices with a focus on archaeology and/or Indigenous ways of being and living. For instance, a group of three students created and tested the strength of cordage, which is fiber strands twisted together to make rope or string. Through testing how much weight their cordage would hold, students were engaged in foundational principles of materials science and engineering.

Discussion

In this paper, we illustrated how an archaeological afterschool program supported middle school learners in the "doing" of science and mathematics practices and concepts; thus, addressing Penuel's (2016) call for more research on ways to support learners in finding new ways to understand their world through STEM. As such, similar to the research of Saxe et al. (2015) and Gutiérrez and Jurow (2016), we made a case for the syncretic approach of ARCH + STEM through highlighting how archaeology and Indigenous knowledges may play a role in middle school learners' engagement with science and mathematics. It was through the afterschool program that participants had opportunities to enact humanistic approaches of STEM processes and practices of archaeologists and Indigenous peoples, as well as enhance and/or connect learners' participation in mathematics and science practices, process, and concepts within a learning environment that is often positioned and defined as an alternative to a more formal learning environment such as a school setting (i.e., two ends of a spectrum; Folkestad, 2006; Lange & Costley, 2015). This was observed through five doings, namely by engaging with math and science concepts as archaeologists, math and science concepts as Indigenous peoples, and a scientific process as an archaeologist. Based on prior literature, it is likely that these experiences supported middle school learners' ability to make connections and reconceptualize what it means to do science and mathematics (Beatty & Blair, 2015), as well as shift their perspective of mathematics and science as a human endeavor that involves collaboration and exploration (Forbes & Skamp, 2019; Kwon et al., 2021).

Educators in this program often questioned if and when to name particular participations as science or mathematics within the afterschool program as the goal was not to engage learners in approaches more common to formal settings. However, we acknowledge how participation in science or mathematics activities through archaeology may foreground learners' developing



practices and knowledge as mathematicians and scientists without their ability to identify and/or explicitly articulate this (e.g., seeds of algebraic thinking; Levin & Walkoe, 2022). Additionally, we acknowledge that the results of this study hold promise in terms of a diverse and inclusive STEM workforce as prior research in informal learning environments has shown the potential to positively develop and maintain youths' interest, identity, and knowledge in STEM (e.g., Vela et al., 2020; Young et al., 2019); factors that have been shown to influence one's decisions to pursue a degree and career in a STEM field (e.g., Godwin et al., 2016; Maltese et al., 2014).

We contend that the significance of this study lies in the potential for professional archaeologists and educators in other communities to develop a similar afterschool program as a way to support learners' engagement with math and science concepts and practices. Based on our experiences, we provide a few recommendations when adapting and/or developing a similar program for middle school learners. First, create and implement archaeological concepts and Indigenous ways of knowing that allow for exploration and application of STEM concepts, skills, and practices that are connected to, yet "hidden" from, formal schooling standards. Second, engage learners in authentic activities that allow them to participate in the practice of archaeology, ones that allow them to struggle or even fail. Third, allow students to follow multiple pathways to achieve the various goals grounded in science and mathematics concepts and practices.

Further, we acknowledge two limitations of this case study. First, observations of the various STEM practices within the program were colored by each individual's perspective, understanding, and experiences as STEM learners and educators. While some may view this as a limitation, we view this as a strength as we were not seeking agreement, but wanted to gain a more holistic picture of how middle school students participated as STEM learners through the afterschool program (Denzin, 1984). Second, lacking the ability to generalize findings from this study may be viewed as a limitation. For example, some may argue that the results from the localized nature of the Indigenous perspectives and ways of doing STEM as not widely applicable to other regions. Yet as argued by Flyvberg (2006), "generalizations are overvalued as a source of scientific development" (p. 12). Lincoln and Guba (1985) proposed a similar argument as Flyvberg and considered transferability, or the extent to which results are transferable to similar contexts, as an alternative approach. Therefore, future research within similar contexts has the potential to generate concrete universals regarding ways to support middle school learners' engagement with science and math through archaeological concepts and Indigenous ways of knowing (Erickson, 1986).



Conclusion

We conclude with the following quote from *A Science Framework for K-12 Science Education* (National Research Council, 2011).

Our expectation is that students will themselves engage in the practices and not merely learn about them secondhand. Students cannot comprehend scientific practices, not fully appreciate the nature of scientific knowledge itself, without directly experiencing those practices for themselves (p. 30).

In this study, we illustrated how learners engaged in and experienced math and science practices and concepts common to archaeologists and Indigenous peoples. This study holds promise for how to engage and enhance learners' science and mathematics concepts, practices, and processes through concepts and material culture that are often not a part of K-12 school curriculum.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. 2005734. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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