It's not just the writing: Designing science notebooks to engage youth in informal environments

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Informal science education programs are often designed to engage youth in scientific practices in a fun, interactive manner that supports development of science identities, often through the inclusion of opportunities to engage with science communication practices. This study examines youth engagement with science communication practices in one informal physics program over the course of two semesters. In this program, youth participants perform experiments alongside adult mentors and document their experiences in science notebooks. We find that shifting the format of the notebook pages away from school-like lines and towards more flexibility of style of communication with a greater emphasis on learning new science vocabulary impacts how often youth engage with communication in the program as well as *how* they explain, discuss, and express their scientific findings. These results suggest that providing more flexible formatting for science communication may facilitate engagement and opportunities for science identity development among youth participants.

I. INTRODUCTION

Informal science education programs provide fun and enriching environments for children to engage in scientific exploration outside of the confines of a traditional classroom. These programs have been shown to have a positive impact on youths' skills, confidence, and knowledge, particularly among students from traditionally underrepresented populations in STEM [1–3]. Many informal programs seek to foster these positive impacts by creating opportunities for participants to engage in authentic scientific practices while developing their own identities as scientists [4]. A key aspect of identity development concerns thinking and communicating like a scientist [5, 6]; therefore, many informal programs provide opportunities to engage with science communication practices, such as reporting results of experiments or using scientific vocabulary in casual conversation with peers. While there is a vast literature on science communication (SciComm), physics education research in the intersection between informal learning environments and SciComm is quite limited [7]. The present work builds on earlier work on the capacities of informal learning environments to promote communication and engagement among youth [8].

This study analyzes youth engagement with communication practices in Partnerships for Informal Science Education in the Community (PISEC), an informal physics program run through the University of Colorado Boulder. While the full program takes place in a variety of environments, this paper focuses on an after-school club format in which youth participants (YPs) perform fun, inquiry-based experiments alongside adult mentors and document their experiences in science notebooks. These notebooks represent a pervasive medium for YPs to express thoughts and findings throughout the program. Our study focuses on the following research question: how does the format of the science notebook impact YP engagement with and communication in their notebooks? Our findings suggest that the format of the notebooks affects not only how often participants engage with communication in the program, but how participants explain, discuss, and express their scientific findings.

II. CONTEXT

The PISEC after-school program connects university volunteers with elementary and middle school youth to engage in hands-on, open-ended physics experiments themed around a central physics curriculum (e.g., mechanics). The program meets at a community partner site (e.g., school or community organization) for one hour per week, 8-10 weeks per semester. The PISEC environment is designed to be distinct from a formal school environment run by teachers; instead, YPs have ownership over how they engage and the university mentors work alongside them as both peers and guides throughout their scientific exploration [9, 10]. During a typical PISEC session, YPs work in groups of 2-5 with one university mentor per group. Sessions often begin with YPs "selecting" one or more experiments to explore by choosing from as many as 30 available Activity Sheets (Fig. 1).

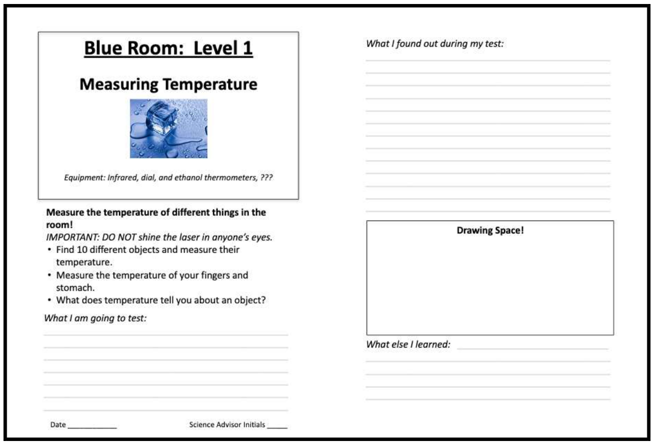
The Activity Sheet serves as both guide for beginning an experiment and space to document notes, findings and other thoughts that arise during and after experimentation. The sheets are hole-punched pages designed to be easily slot into a YP's science notebook (a 3-ring binder) when they are finished. Though by no means the sole avenue of communication, these sheets serve as one of the primary methods for PISEC YPs to engage with authentic scientific communication practices. However, writing on these sheets is voluntary, and many students opt not to engage. Previous research found writing on these sheets to be one of the least popular parts of the program [10]. Additional observations from community partners and program designers noted that YPs were not engaging much with Activity Sheets or their notebooks, which limited their opportunities to see the growth in science identity and engagement with scientific practices that we anticipate communication in the notebooks can facilitate. These suggest that the previous format of the Activity Sheets could be altered to structure communication practices in a way that better resonates with youths' interests and skills.

III. METHODS

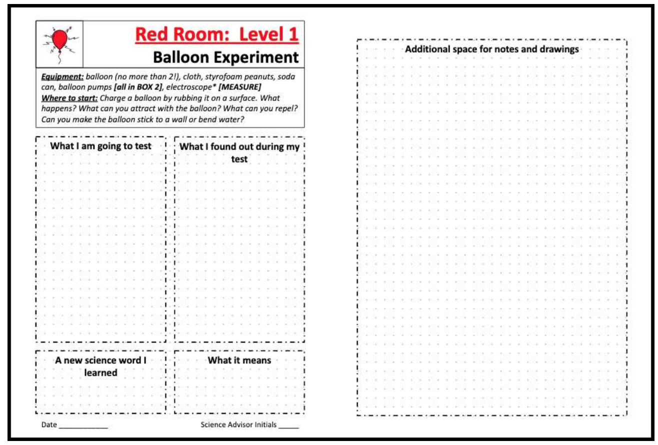
We examined the style and content of YP engagement with two different formats of Activity Sheet implemented in Spring and Fall 2023, respectively. Fig. 1a shows an example of a typical Activity Sheet from Spring 2023 (SP23). The front of the sheet indicates a colored room (e.g., "Blue Room") which specifies a curriculum subtopic (in this case, temperature) and a "level", which specifies the depth of the activity (in this case, introductory). Each experiment is titled, and an included graphic hints at the subtheme associated with the room color. Each sheet lists necessary equipment and gives a few launch points that YPs can use to begin their explorations. As a bit of guidance for structuring their thoughts, YPs are prompted to describe (1) "What [they are] going to test" before or during their experiment, (2) "What [they] found out during [their] test" during or after their experiment, and (3) "What else [they] learned" for anything else that pops up. A small box is provided in case YPs would like to include drawings of their experiments; otherwise, prompts are followed by lines for written responses. While other pages in the SP23 notebook prompt students to record scientific vocabulary, no explicit prompting occurs on these pages.

Fig. 1b shows an example of the changes made to Fall 2023 (FA23) Activity Sheets. All prompts have been moved to the front of the sheet. Explicit drawing space has been removed in favor of open boxes with dotted backgrounds underneath each prompt. Scientific vocabulary is now front and center, with two boxes prompting YPs to consider "A new science word [they] learned" and "What it means".

Both Activity Sheets were implemented at the same PISEC site over the course of 6 sessions in SP23 and 8 sessions in FA23. This site was conducted in partnership with a com-



(a) A typical SP23 Activity Sheet features 3 prompts, lines for written responses, and explicitly indicated "Drawing Space!"



(b) A typical FA23 Activity Sheet features 4 prompts, open boxes with dotted backgrounds, and explicitly prompted engagement with scientific vocabulary.

FIG. 1: Sample Activity Sheets for SP23 and FA23 semesters. "Blue Room" (left) and "Red Room" (right) indicate a curriculum subtopic, while "Level 1" indicates that the activity serves as an introduction to the subtopic.

munity organization that works with marginalized youth in a cohort model, providing robust programming designed to foster skills necessary to successfully navigate school, college, and beyond. Across the two semesters, the PISEC program at this site worked with the same cohort of 26 students, who were in 3rd/4th grade in SP23 and in 4th/5th grade in FA23. All YPs at this site were from low-income families, and most were Hispanic/Latine. Many of the participants were English Language Learners (native Spanish speakers).

Due to the nature of continued partnerships in PISEC, university volunteers and the physics curriculum differed from semester to semester (e.g., thermodynamics in SP23 and electricity and magnetism in FA23). All factors may have a slight impact on the degree to which YPs engage with written communication in the program; however, sessions from both semesters were facilitated by the same site leader (first author), which may have helped mitigate this effect.

We conducted a qualitative coding analysis on 168 (61 SP23, 107 FA23) Activity Sheets using a combination of *a priori* and emergent codes. Activity Sheets were broken into regions delineated by prompts and coded for word count and content. Coding was done by one researcher (lead author); a second researcher (last author) coding a random subset of all pages resulted in an average inter-rater reliability of $94 \pm 2\%$ agreement, which rose to 100% agreement after discussion and clarification of coding definitions.

A priori codes included codes for word/drawing count and presence of "scientific vocabulary", defined for the purpose of this study as words used "in a science context that are not common in daily conversation among children, or in a way that differs from how they are used colloquially" (e.g., "magnetism" or "heat"). While investigating the content of Activity Sheets, we identified emergent themes related to traditional "scientific practices". These codes corresponded to one or more of a number of "steps" of the scientific method [11], including: offering explanations, making observations, giving predictions, setting procedures, asking questions, and proposing tests. Here we present only a subset of codes included in the full analysis. Due to low counts in some examined categories, all associations were tested with a Fisher's Exact Test with $\alpha = .05$.

IV. RESULTS AND DISCUSSION

A. Style of Communication

Writing. There was no significant difference between the number of SP23 and FA23 Activity Sheets that contained writing, ($p = .14$), as summarized in Table I (next page). However, of the sheets that contained writing, SP23 sheets had higher overall word counts than FA23 sheets ($p = .01$). This variation supports the idea that lines under prompts encourage YPs who are already writing to write more.

This impact of formatting on written engagement is further supported by data from an atypical program session in SP23. During this visit, rather than choose their own activities, all YPs participated in the same activity: Coke and Mentos, henceforth C&M. Following the C&M activity, authority figures associated with the community group, but external to PISEC, explicitly encouraged YPs to document their findings on the appropriate Activity Sheets. This heavily directed approach is counter to our commitments for informal learning that offer opportunities for youth agency. In the more formal environment fostered by the presence of these authority figures, all Activity Sheets included writing, and tended towards significantly higher word counts than traditional SP23 visits and all FA23 visits ($p = .009$ and $.008$, respectively).

These findings together suggest that the structure provided by the Activity Sheets impacts the amount of writing provided by YPs in this program, with a more rigid, formal structure (given by lines) favoring higher word counts than less formal formats (open boxes with dot grids). One possible interpretation is that both the presence of lines and the presence of external authority figures during the C&M visit foster a more school-like environment where YPs are implicitly and explicitly told that "the correct way to engage" with their notebook is through writing. In formal school environments, higher word counts are often associated with higher effort or more active participation and therefore higher grades.

Drawing. The shift in format had a significant impact on the number of drawings on Activity Sheets. Despite the presence of the explicitly prompted "Drawing Space!" on the back of the SP23 sheet (Fig. 1a), the more flexible open-box format in FA23 increased the number of Activity Sheets with at least one drawing from 24% in SP23 to 52% in FA23 ($p < .001$). 19% of these drawings appeared alone on pages without additional writing. This reinforces initial observations that open boxes supported YPs who wanted to draw.

When taking into account both writing and drawing as forms of communication, FA23 showed a significant increase over SP23 in the amount of communication, with 73% of all pages containing at least one instance of writing or drawing compared to 61% in SP23 ($p = .045$). This finding suggests that despite lower word counts, the shift from lines to open boxes successfully increased YP engagement with the sheets.

B. Content of Communication

In addition to investigating quantity of engagement with the science notebooks (via word and drawing counts), we also examined the content of words and drawings.

Drawings. The content of drawings found on Activity Sheets is summarized in Table II. Drawings varied from simple doodles of hearts or smiley faces to complex depictions of circuits or scientific equipment. Researchers identified two concrete elements that appeared throughout drawings from all three categories of Activity Sheets: Doodles, which include stars, smiley faces, or other drawings that are seemingly unrelated to a particular activity and Equipment, which include materials associated with the activity or its setup.

One interpretation of the decrease in doodling (from 31% to 4%, $p = .008$) is that increased flexibility in communication style allows YPs to focus their drawings on other things, and could even help to facilitate more engagement with the actual activities. This is supported by the significant increase from SP23 to FA23 in the number of drawings related to elements of the experiment, e.g., drawings depicting equipment or associated with scientific practices ($p < .001$ in both cases). The content of FA23 drawings aligns with those from the more school-like C&M visit; however, while those arose in part due to influence from authority figures, the FA23 drawings came about without such presences.

While most images appear without text, many are accompanied by captions (bottom row, Table II). In some cases, these captions serve as the primary form of communication, with the picture serving as emphasis or further explanation. In others, drawing takes a more central role.

Figure 2 (next page) shows an example of how drawing and writing can be used together to express scientific findings. In this activity, YPs investigate moving charges in a magnetic field using a long extension cord as a jump rope. An attached multimeter displays the current generated by the rope as it swings through the Earth's magnetic field. The left box, labeled "What I am going to test" contains a drawing of three stick figures jumping rope, and is captioned "Jump! ZZZx". The right box, labeled "What I found out during my test", depicts a current measurement on the multimeter. Here, the drawings serve as the primary method of communication, with the single word "Jump!" serving to emphasize the content of the drawing. The low word count does not correspond to a lack of effort or engagement with the scientific process; instead, the open-box format allows for more flexibility in *how* this YP participates and communicates what they found

TABLE I: Style of communication per Activity Sheet. ns give the total number of Activity Sheets per category; percentages are fractions of n. Significant differences between SP23/FA23, Typical SP23/C&M, and C&M/FA23 sheets are **bolded**, underlined, and *italicized*, respectively.

Style	SP23 Typical ($n = 51$)	SP23 C&M ($n = 10$)	FA23 ($n = 107$)
Writing	59%	*100%*	*60%*
1–10 words	33%	20%	44%
11–20 words	16%	40%	12%
21+ words	10%	40%	4%
Drawing	**24%**	50%	**52%**

TABLE II: Content of drawing per reference. ns give the total number of drawings. Content codes are not mutually exclusive. Some sheets contained more than one drawing. Significant differences between SP23/FA23 and Typical SP23/C&M sheets are **bolded** and underlined, respectively.

Drawing Content	SP23 Typical ($n = 13$)	SP23 C&M ($n = 5$)	FA23 ($n = 73$)
Doodle	**31%**	0%	**4%**
Equipment	**46%**	100%	**90%**
Scientific Practice	**8%**	60%	**58%**
Captioned	**15%**	40%	**42%**

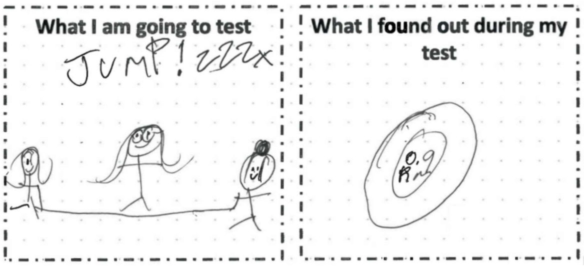


FIG. 2: Drawings communicate scientific discoveries. Panel 1 (left) is labeled "What I am going to test", and shows a drawing of three stick figures jumping rope with an extension cord, captioned "Jump! ZZZX". Panel 2 (right) showcases what they discovered through a depiction of a measurement made on a multimeter connected to the cord.

important about their explorations.

Scientific Practices. The new format of Activity Sheet did not show any significant positive or negative impact on engagement with any of the examined elements of scientific practice (all $p > .08$). Table III focuses analysis of the broadly coded scientific practices to two key facets prominent in Activity Sheets from both SP23 and FA23: explanations and observations. Observations take many forms, and often serve as the foundation for scientific exploration. Likewise, explanations showcase findings and represent the culmination of scientific exploration. Shifting the format of the Activity Sheets allowed for greater flexibility in how YPs communicate while preserving important elements of the scientific process; more than that, the slight increase from SP23 to FA23 has practical implications for how the new format might encourage YPs to articulate complex observations and explanations in a manner unique to their own communication style.

Vocabulary. There was a significant increase ($p = .002$) in the amount of scientific vocabulary present on Activity Sheets from SP23 to FA23 (Table III, bottom row). This can be directly connected to the inclusion of the "... new science word I learned" prompt, as 42% of all science vocabulary words from FA23 appeared in the box under this prompt. However, vocabulary was not confined to this box: new vocabulary words appeared alongside images as captions, in explanations of physical phenomena, and in definitions of other scientific vocabulary. The widespread prevalence of scientific language shows promise for the development of science communication practices.

TABLE III: Scientific practice codes per sheet. ns give the total number of pages per category. Significant differences between SP23/FA23, Typical SP23/C&M, and C&M/FA23 sheets are **bolded**, underlined, and *italicized*, respectively.

Scientific Practices	SP23		FA23
	Typical	C&M	
	($n = 51$)	($n = 10$)	($n = 107$)
Explanation	10%	10%	18%
Observation	33%	*90%*	*42%*
Vocabulary	**2%**	10%	**19%**

FIG. 3: Sometimes, a picture is worth a thousand words. Panel 1 (left) is labeled "A new science word I learned", and features two handwritten words: attract and repel. Two illustrations in Panel 2 (right) serve as definitions of these words, and show two magnets close together and far apart.

In Figure 3, a YP takes advantage of the flexibility afforded by the open-box format to explain difficult concepts. On the left, the YP lists two new science words that arose during an exploratory activity involving magnets: "attract", and "repel". On the right, the YP provides definitions not with words, but with pictures of oval-shaped magnets being brought together and pushed apart. The physical concepts of "attraction" and "repulsion" are difficult to describe with words, especially for those not already familiar with how to talk about other physical systems. Yet this concept is quickly summed up with two accurate, easily understandable drawings. Their drawing and writing work together to introduce and provide a concise explanation of a challenging concept.

V. CONCLUSIONS

Through a qualitative coding analysis of communication in PISEC science notebooks, we find that the formatting of Activity Sheets impacts both the quantity and content of youth communication in the PISEC environment. By shifting the format of provided materials away from formats that evoke more school-like associations towards those that allow for a wider variety of communication styles, we open opportunities for participants to engage more deeply with elements of scientific communication in a manner that more closely aligns with their interests. Future work looks to conduct further analysis of the impacts of specific wording of prompts to scaffold engagement with the scientific process, as well as extend findings to other student populations within PISEC.

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