ASTRO BEAT

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The author doing the "Make Your Comet" activity in an elementary school class in Hilo, Hawaii in 2018.

Getting Better at Science Education & Outreach as an Astronomer

By Xinnan Du (UC Riverside)

I started my outreach journey in my second year of astronomy graduate school at UCLA, when I served as a volunteer for the first time in the department's outreach team, *Astronomy Live!*. Now 6 years later and after earning my PhD, not only have I become the official outreach lead in the Astronomy Department at UC Riverside, but also doing informal science education has become my long-term career plan that I'd love to devote myself to. It has surely been a long way, and with some detours. When I was merely a volunteer, all I cared about was how to get the audience excited about what I was presenting. When I later became the coordinator of the department's outreach program at UCLA, I kept running the program the same way as it had been before. It was not until then did I ask myself, how can I improve my

outreach skills, how can I make this program better, and how do I know if it has become better or worse? The questions had lingered for a while and I couldn't find a proper way to tackle them.

Luckily, I got a chance to finally get into the Education and Public Outreach (EPO) world when I formally got trained on assessment-driven STEM[1] Education. The participation in the Professional Development Program (PDP), organized by the Institute for Scientist & Engineer Educators (ISEE) at UC Santa Cruz, completely changed my perspective on assessments and EPO as a whole. Rather than adding the evaluation to a completed activity as the last step, I learned that evaluation should guide both the development of the lesson plan and the teaching.

An Assessment-Driven Adaptation of a Popular Astronomy Activity

Let's take the "Pocket Solar System" activity as an example (see Night Sky Network version at https://nightsky.jpl.nasa.gov/download-view.cfm?Doc_ID=392). This hands-on activity asks the audience to (a) create a solar system to scale on a paper roll with planets marked in correct positions; and (b) learn basic facts about each planet. This activity can be carried out at different levels, both with K-12 students and adults. Figure 1 is a picture from when I presented this activity in a 3rd-grade classroom. Admittedly, the activity may look slightly different for kids and adults. You could encourage younger audiences to draw the planets in

Figure 1. The author doing the "Pocket Solar System" activity in a 3rd grade classroom in Hilo, Hawaii in March 2020, as part of the Journey Through the Universe program organized by the Gemini Observatory.

detail and get them excited, but ask adults to only write down the planets' names and get straight to the point. However, regardless of your audience's level, questions an astronomer or educator may want to keep in mind when trying out this activity include:

1. What are the specific learning goals of this activity or lesson? Try to be specific. Answers like "to learn about planets in the solar system" are a good start but not enough. For example, what are you hoping that the audience achieves by the end of this activity? Which

1 STEM = Science, Technology, Engineering, and Mathematics

properties of the planets are you going to focus on? Try to start your sketch of the learning goals with "students will be able to…" if you find that helpful. Answers such as "students will be able to visualize the relative distance among planets, and differentiate rocky and gas planets" are much better.

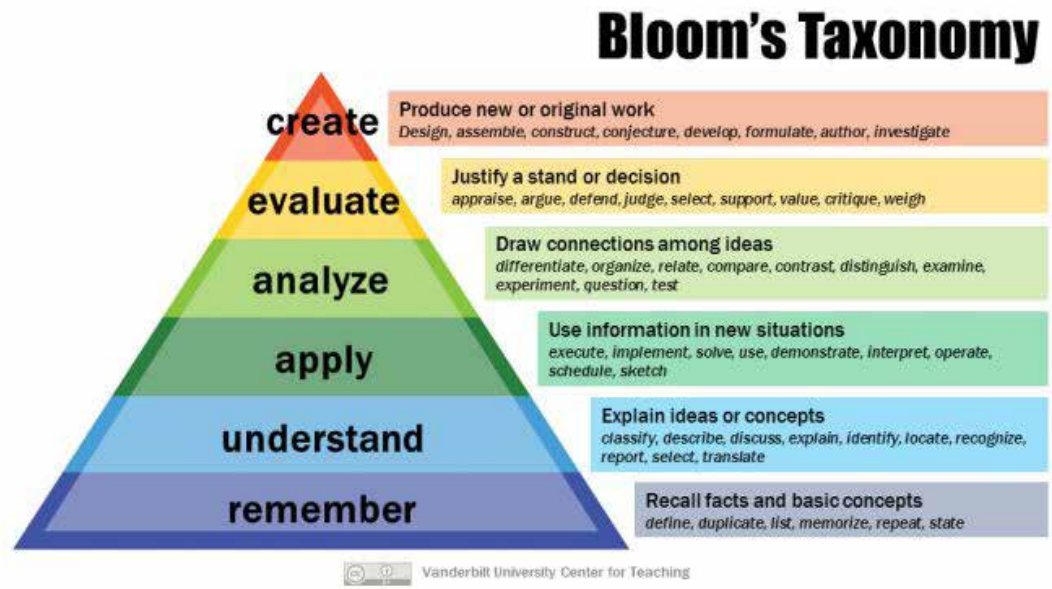

Figure 2. Bloom's Taxonomy, a classification of learning objectives at different levels. The "measureable" verbs to be included at each level of the learning outcomes are suggested. The bottom layer of the pyramid represents the most basic level of learning (memorizing and repeating facts) while the top of the pyramid represents the highest level of learning (creation of new, original work).

2. How could you evaluate whether the learning goals are achieved? This again requires that you be specific about the learning goals, especially about the use of the "verb" in the learning goals. "Learn", "understand", "know" are common words we tend to utilize, but be aware that these are very vague and not easily measureable. Instead, verbs like "articulate," "identify," "categorize" are specific enough and also explicitly signal how you should conduct the evaluation. Figure 2 demonstrates Bloom's Taxonomy, a collection of verbs recommended in defining measureable learning outcomes at different levels. Now, with our previous example, we can further refine our learning goals into (a) "students will be able to point out that planets in the inner solar system are more closely located than those in the outer solar system;" and (b) "students will be able to categorize planets into rocky and gas types based on planetary sizes and compositions."

3. In which format are you going to assess the participants (and their learning gains)? Guided by the previous learning goals, now we need to create opportunities for the audience to "show" that they've got it. For learning goal (a) above, assessments can be done through questions like "do you notice any general patterns in the spacing of planets from the inner to the outer solar system?" As for (b), a worksheet could be created with some recently discovered exoplanets. Students would apply the newly-learned "rocky" and "gas" planet concepts to new, real-life cases, and solve problems.

When conducting evaluations like this, *why* and *when* to do them also make a big difference. They are two different types of assessments we normally use, "formative assessment" and "summative assessment,"

which focus on different aspects of the activity/program, and provide valuable, multidimensional information when combined. Formative assessment evaluates the audience's knowledge, opinion, and level of engagement **during** the activity, to make **adjustments** to the remainder of the activity or the next iteration of a similar activity. Summative assessment, on the other hand, evaluates how well the objectives, either high-level or specific, of the activity/program have been achieved **after** it has been conducted, as a **result.**

In-Person Evaluation: On-the-Spot Feedback

Using formative assessment appropriately and adequately can lead to great outcomes. Let's put everything into context again using the same "Pocket Solar System" activity. As a speaker, multiple on-the-spot-feedback (OTSF) tactics can be used to continuously gather information from the audience and engage them throughout the learning process.[2] These include asking audience questions, using models, polling, think-pair-share, audience drawing, and more.

For instance, asking the students at the beginning of the activity "how many planets are there in the solar system?" or "which planet is the closest to Earth?" can gauge their overall level and prior knowledge of the topic, and also identify if they have any pre-existing misconceptions that you need to address beforehand. If many students say "9 planets" or "Mercury," you know you'll need to stick with the basics, at least to start with. If the answers are more like "8 because Pluto is a dwarf planet" or "Venus and it's a twin planet of Earth," then congratulations, conversations can go a lot beyond the activity itself.

Typically I don't like to "spoil" the exciting or surprising part of the activity too much, especially when I know that specific content will be covered at some point during the activity. So even though the majority of the kids may think Mercury is the closest planet to Earth, I will leave it as "we will see" at the beginning, and surprise them later when introducing Mercury's real position in the solar system. Some misconceptions, however, need to be clarified as soon as they emerge, particularly if you will never come back to the topic again. For example, when most of the students think that there are 9 planets in the solar system but you were not planning to focus on talking about the definition of planets, it's probably good to explain why Pluto is no longer considered a planet before starting the activity. Otherwise, that pre-activity assessment will just be wasted: you know that there was a problem, but you let it slip through.

Similarly, using the tactics in the middle of the activity enables you to gauge whether the audience is following you, and more importantly, to make them an indispensable part of the science "explorations." To be honest, sometimes you can get a significant amount of feedback just by looking at the audience's faces: are any of them napping, yawning, or looking at their

2 I was recruited for and have served as a design tester for the ASP's On-the-Spot Feedback (OTSF) project, an NSF-supported grant that aims to develop and provide practical science communication and assessment strategies for scientists doing public engagement events. As a design tester, I tried out some of the project's OTSF tactics, and reflected on my experience using them in different outreach settings.

Figure 3. The public viewing of Mercury Transit at UC Riverside, organized by the author in November 2019. The event attracted around 300 people from the local community (primarily families). A post-event survey was sent to the attendees to evaluate whether this event had increased their interest in astronomy and STEM in general.

cellphones? Do some of them look bored and confused? If the answer is "yes," you have lost some of them already and it's time to bring their attention back. At this point, asking them to draw something or do a think-pair-share activity could reactivate their critical thinking and enable a true two-way science dialog if the setting allows.

Finally, the summative assessment should be conducted according to the learning outcomes identified previously. If at the end of the activity the students fail to describe in their own words that the outer planets are a lot more sparsely located than the inner planets, or to apply the "rocky" and "gas" planet definitions to the categorization of new objects, you know something did not go quite as hoped for. In that case, you may want to revisit your lesson plan, identify the cause for that, and incorporate more or different strategies, prompts, and tactics next time. To identify the issue, you might ask questions like: Was it because the students weren't paying attention? Was it because you didn't make it clear or emphasize the point enough? Or was it because the learning goals were way beyond the students' level to achieve?

Program Evaluation

On a higher level, if you are the director or manager of an outreach program instead of simply a one-time presenter/volunteer (and I've got experience with both; see Figure 3 from an event I organized and managed), evaluations are even more vital in keeping the program running in a healthy way. Program evaluation also starts with "objectives," asking for instance *what do you want to achieve through this program?* Typical objectives of outreach programs include "increase the interest in STEM fields and STEM-related careers," "increase the participation of underrepresented minority groups in STEM," and "increase the interest in pursuing higher education and/or an advanced degree." Of course the above goals are generic, and in reality you may have specific goals tailored to the needs or interests of your organization or stakeholders.

This kind of higher-level assessment is very challenging to carry out based just on in-person interactions, as you normally lack a direct measure of the audience's attitudes. You could qualitatively tell by whether the participants look excited when talking to you about

science, but the level of "excitement" is not quantifiable that way. Instead, incorporating questions in a survey would make it easier and more direct. You would need the respondents to self-report the "change" in their interest or attitude, which could be tricky if the wording of the questions is implicative. For example, people naturally tend not to say "no" much if they don't feel strongly against a statement. So simply asking "do you have an increased interest in STEM fields?" may give you some false positives, especially when there are limited choices of answers with only "yes" or "no."

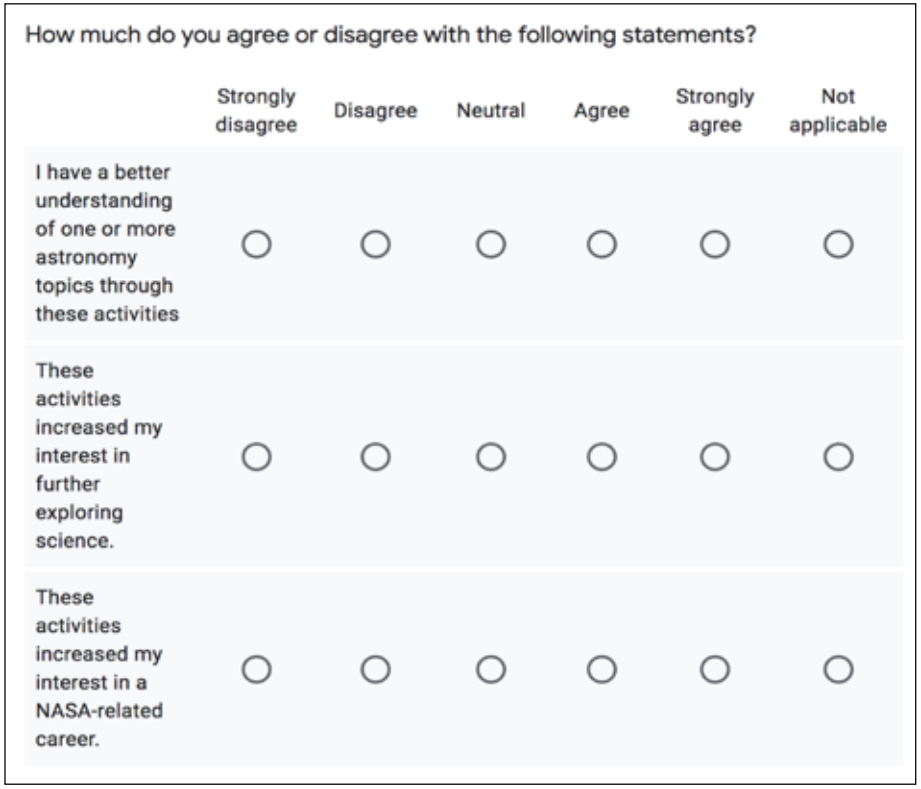

Figure 4. An example of how program evaluation is incorporated in post-event surveys. The questions are in one-to-one projection to the specific program objectives. In this case, the survey is part of the evaluation of a NASA-funded EPO program, and therefore has a specific goal in increasing interest in NASA-related careers.

A better approach to avoid this kind of biased results, introduced by wording and a lack of dynamic range in choices, is to ask people to rate how much they agree with a specific statement. Questions could be phrased as: "On a scale of 1 to 5 (1: strongly disagree; 2: disagree; 3: neutral; 4: agree; 5: strongly agree), how much do you agree with the following statement: my interest in STEM fields has increased after this event." Figure 4 shows an example survey item, where the question has been developed to reflect the specific objectives of the program I currently manage. Alternatively, we can ask the respondents to rate their interest in STEM fields before and after the event separately, both on a scale of 1 to 5, and calculate the difference in a statistical manner.

Evaluations are key to guide teaching, learning, and educational/outreach programming. They should not be treated simply as an "add-on" or "nice-to-have" in programs or activities. On the contrary, they should be core to why we are doing outreach and how we know whether we have done it well. Incorporating many evaluation strategies at once could be very intimidating and overwhelming, and some may not even be most suitable to your given context. It has taken me years to learn all the things above, yet I'm still practicing and trying to incorporate new strategies informed by education research, and from best practices in science communication. From my personal experience, I'd like

to share with you the following if you are thinking about garnering helpful feedback from audiences and evaluating your outreach:

- Don't take any feedback personally. The event participants overall love and are grateful for what you have done. Their feedback is simply meant to help you make your events better.
- Take baby steps, keep "assessments" in mind, and incorporate the strategies when you can and feel comfortable.
- Don't wait to be "perfect" before you set out to do outreach, as you will never reach that stage (and in fact you don't need to). Outreach is an iterative process, and we can't learn or progress without actually doing it and making mistakes.

About the Author

Xinnan Du is the Outreach Director and Program Manager of the NASA MIRO FIELDS (Fellowships and Internships in Extremely Large Data Sets) program at UC Riverside. She got her PhD in astronomy in 2018 from UCLA, and her research focuses on the physical properties of the gas in distant star-forming galaxies. Xinnan is very enthusiastic about K-12 STEM outreach and has a long-term career goal in informal science education. She has received formal training in inclusive and inquiry-based STEM education, and been contributing to multiple ongoing projects in the Education and Public Outreach community. Having led numerous large-scale campus-wide outreach initiatives, Xinnan hopes to inspire the younger generation in STEM through hands-on experiences.

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