Enriching undergraduate experiences with outreach in school STEM clubs

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Abstract

The need for a more robust, well-trained STEM workforce is becoming increasingly acute in the U.S., and there is a clear need to recruit and retain a larger and more diverse population of undergraduate STEM majors. While numerous efforts to improve engagement and support in the traditional P-16 classroom have been implemented successfully, it is also critical to explore other types of activities that have potential for high impact. The STEM Club Leadership for Undergraduate STEM Education, Recruiting and Success (STEM-CLUSTERS) project at our large public research university in the Mountain West presents an outreach model to engage undergraduate STEM majors in developing and facilitating activities in local middle and high school STEM clubs. Through case studies, built upon data from reflective journals and semi-structured interviews, the project has identified a number of benefits to the first cohort of participants, which is comprised of eleven undergraduate students operating in interdisciplinary teams across five schools. In this paper we describe the essential elements of our outreach model and suggest benefits related to undergraduates' content knowledge, metacognition, communication skills, and identity as a future STEM professional.

Introduction and Background

One of the most pressing challenges facing the United States in the coming decades is the need to recruit, train, engage and retain a diverse, well-prepared workforce in Science, Technology, Engineering and Mathematics (STEM) (Stine & Matthews, 2009, National Research Council, 2010; PCAST, 2012). The need is particularly pressing from traditionally underrepresented populations in STEM (Harper & Newman, 2010; National Center for Science and Engineering Statistics, 2013; Cole & Espinoza, 2008). Participation in after-school, summer and other informal STEM programs is viewed as an experience that is critical to positive outcomes for learners (cf. Augustine, 2005; Chubin, Donaldson, Olds & Fleming, 2008; NSF, 2015).

Documented benefits for participants in informal STEM programs include an increase in attitudes and interest in science and technology (Hayden *et al*, 2011) and a stronger understanding of STEM concepts and processes (McGee-Brown *et al*, 2003). In-school communities can play a significant role in encouraging students to consider further study and careers in STEM (Aschbacher, Li and Roth, 2010). Likewise, STEM outreach programs can support improved perspectives of STEM, STEM professionals (Laursen, Liston, Thiry & Graf, 2007) and an increased likelihood of pursuing a STEM major (Sahin, 2013). Organizing and implementing outreach activities can promote outreach providers' ownership of their own learning and nurture a sense of belonging and engagement (Abernathy and Vineyard, 2001). There is, however, a paucity of research on undergraduate STEM majors in K-12 settings and the outcomes related to their experiences in the context of outreach.

We present a model that, we assert, broadens the STEM education experience for undergraduate outreach providers (hereafter referred to as "Fellows"), specifically with respect to the development of their content knowledge, metacognition, communication skills and STEM identities, through immersive experiences. We leverage communities of practice (Lave & Wenger, 1991) as a theoretical lens and guiding framework for our model.

Community STEM Clubs

While our model can be applied to a variety of outreach settings, our program specifically tasks undergraduate STEM majors with organizing in- and after-school STEM clubs and teams in middle and high schools. The STEM CLUSTERS project, funded by an NSF Improving Undergraduate Science Education (IUSE) award, organized five STEM clubs at partner schools in the metropolitan area (Table 1).

Table 1. Summary data for partner schools in Year 1 of Community STEM Clubs (CSC) program

School	Club Type	Total Enrollment	%URM ¹ Students	% Free or Reduced Lunch
Gold Meadow High School (GMHS)	High School STEM Club	1126	20%	25.1%
Young International (YIA)	Middle and High School TSA ² Chapter	734	82%	70.7%
Larimer High School	High School	1313	35%	24.8%

(LHS)	TSA Chapter			
Eastern Leadership Academy (ELA)	Middle School STEM Club	74	19%	31.1%
Western Regional High School (WRHS)	Hydrogen Fuel Cell Automotive Team	1309	44%	46.2%

¹ Black, American Indian, Alaska Native, Asian-Pacific Islander, Hispanic or Latino

² Technology Student Association (TSA) is a national student organization that aims to foster personal growth, leadership and opportunities in STEM

Core Tenets of our Outreach Model

The intent of the project is that the four central components of our model collectively enrich the undergraduate's experience, contribute to student learning, personal growth, and strengthen communities of practice.

Full Student Responsibility for Outreach Planning and Execution

The model requires the Fellows to take responsibility for research, planning and execution of activities and demonstrations. While faculty mentors and lead teachers provide feedback and support, the “ownership” of the outreach process lies with the Fellows. This does not mean that Fellows must create activities and demos from scratch, rather they will often modify existing activities from well-vetted online repositories.

All Fellows complete a three-day summer training workshop and team planning session to prepare them for their outreach experience in STEM clubs. The workshop includes an overview of resources, a discussion with outreach-experienced peers, discussions on effective communication and classroom issues, and advice from lead teachers. The workshop culminates with each team delivering a 10 to 15-minute overview of their plan for the first six weeks of the semester, with feedback from their peers and faculty.

STEM Communications Seminar

At the heart of STEM outreach is the need to clearly communicate difficult topics to an often varied and sometimes challenging audience. This skill is also crucial for future STEM professionals in order to further public understanding of science (cf. Weigold, 2001; von Winterfeldt, 2013), and function more effectively within teams. The Fellows' growth as STEM communicators is supported by a key component of the STEM CLUSTERS outreach model: the (1-credit) STEMmunication seminar.

Each month, Fellows meet to explore effective STEM communication through written, audio (podcast), video and oral presentations. Fellows are asked to find and analyze examples of these media, and determine effective and ineffective practices across the media. While there is often a great deal of conversation related to their core task of communicating with middle and high school students, the course focuses on communicating STEM to all audiences. STEMmunication also serves as an important part of Fellows' mentoring and support, as it allows them to discuss the challenges and successes they encounter in their clubs. These regular meetings create and nurture a community of practice in which participants develop understandings, norms, relationships and identities relevant to their roles as outreach Fellows (Handley et al., 2006).

Support from Peers and Faculty Mentors

Our model includes support mechanisms that allow Fellows to draw upon the experiences of faculty mentors and their peers. In each meeting of the STEMmunication course, the discussions of the Fellows' recent outreach experiences give an opportunity for meaningful support and mentoring for the Fellows. Faculty share experiences that inform planning for upcoming club activities and contribute to the class discussions on different modes of STEM communication.

The "share-out" portion of the STEMmunication course allows students to candidly discuss their experiences. The Fellows provide each other with tips and give support to each other as they navigate the challenges of their outreach assignments. Our recognition of the importance of peer support arises in part from interviews with and reflections by the initial 2015-16 cohort of Fellows, who identified the value of this peer interaction.

In addition to faculty and peer support throughout the STEMmunication course, each team is observed each semester by a faculty mentor. Through this observation, suggestions are provided to support future activities and growth. In class support is also given by the lead teachers at each partner school.

Reflection

At the outset of the STEM CLUSTERS project, written reflections and structured interviews provided initial research data. As the project has progressed, however, the value of reflection to the Fellows has become more significant, and we now recognize this activity as a key driver of their growth.

Introspective teaching and learning has been shown to be valuable in a number of settings. The process of critically assessing one's teaching is a central part of reflective pedagogy (Zeichner & Liston, 2013), as it allows an educator to disentangle their perspectives and contexts from those of their students (Brookfield, 1995). In our setting, Fellows are asked to reflect on the design and outcomes of their activities, and to consider if they met the goal of engaging participants through STEM content. This process encourages the Fellows to continuously evaluate their viewpoints on STEM communication, equity, and the nature of STEM and STEM learning.

Tanner (2012) notes that reflective journals are an effective method to build metacognitive awareness in students, as is awareness of diverse learning strategies (Pintrich, 2002; Zohar & David, 2009). Determining and reflecting on how to best promote learning in their clubs, and explicitly writing and verbalizing their observations on teaching/learning strategies and problem solving approaches, serve as drivers of metacognitive growth in the Fellows.

Theoretical Foundations

We contend that learning occurs through social participation (Lave and Wenger, 1991; Sfard, 1998; Vygotsky, 1978) as well as through the acquisition of knowledge. The rich type of participation necessary for developing meaningful epistemologies (Elby & A-Sep Hammer, 2001) and mental models (Redish, 1994) occurs as individuals engage within communities of practice. Further, expertise develops as participants become more involved in that community (Lave & Wenger, 1991; Chi 2006), and are doing so in a meaningful way. Therefore, learning

occurs *through* participation and being a participant refers to “a more encompassing process of being active in social communities and constructing identities in relation to those communities” (Wenger, 1998, p. 4). Figure 1 depicts our conceptual model.

FIGURE 1. COMMUNITIES OF PRACTICE WITH SHARED OUTCOMES FROM OUR OUTREACH MODEL

Content knowledge and *communication skills* are related to participation in these communities, whereby Fellows’ interactions augment their abilities to understand and convey information in ways that support meaning-making processes at multiple levels. Metacognition, though a decidedly more cognitive construct, is shaped and developed as Fellows work with others, observe problem solving strategies, and make explicit their own contributions to a group (Pintrich, Marx & A-Sum, 1993; Pintrich, Wolters & Baxter, 2000; Schraw & Moshman, 1995). Identity is shaped by participation that involves understanding the self in relation to individual and collective norms within communities of practice (Handley et al., 2006). We situate Fellows’ identity in relation to their views of STEM and perceived competencies as a future STEM professional.

Summary of Shared Outcomes for Outreach Fellows

Each STEM club is conceptualized as a case, and all clubs and Fellows together comprise a set of interrelated cases. Our case study approach is meant to situate the Fellows within distinct communities of practice and along varied dimensions of learning.

A diverse collection of undergraduate students participated in the CSC program during year one (Table 2). This includes STEM majors with prior degrees in the arts, a U.S. navy veteran, a retired firefighter, and a majority (8 out of 13) of women representing a range of ethnicities. We focus on the eleven Fellows who participated for the entire year, and also omitted the four participating graduate students, as our focus is on undergraduate experiences and outcomes.

Table 2. Summary demographic data for undergraduate outreach Fellows in 2015-16 CSC clubs.

School	Name	STEM Major	Gender	Ethnicity
Gold Meadow High School (GMHS)	Delilah	Biology	Female	Hispanic
	Nora	Math/Bio	Female	White
Young International Academy (YIA)	Sandra	Bioengineering	Female	White
	Karl	Mech. Eng.	Male	Asian Am.
	Marcus	Elec. Eng.	Male	White
	Colleen	Psych/Econ	Female	White
Larimer High School (LHS)	Kelly	Math	Female	Hispanic
	Aaron ¹	Bioengineering	Male	White
	Joel ¹	Mech. Eng.	Male	Hispanic
Eastern Leadership Academy (ELA)	Burt	Math/Bio/ Psych/English	Male	White
	Allison	Biology	Female	White
Western Regional High School (WRHS)	Sharon	Mech. Eng.	Female	Black
	Lorna	Mech. Eng.	Female	White

¹ Participated for one semester.

Multiple sources of data were gathered from each Fellow including a *personal biosketch*, which provides valuable insights into each Fellows' background and prior experiences, two *semi-structured interviews*, and monthly *reflections*. Interviews and reflective prompts included questions related to content knowledge, communication skills, metacognition, and identity.

Each member of the research team completed an independent reading and analysis of all data related to each Fellow and within the context of the corresponding school STEM club. Emergent patterns in the data were identified using open coding in an iterative process of inductive analysis that aligned with the outreach model and shared outcomes of content knowledge, metacognition, communication, and identity (Figure 1).

Evidence of Shared Outcomes: Young International Academy

In this section, we present evidence for some of the shared outcomes (mentioned in Figure 1 above) through the case of Young International Academy (YIA). We highlight YIA as it was the only CSC club organized wholly by undergraduates, and the Fellows provide a good snapshot of the breadth of students and academic majors involved in the CSC program. The shared outcomes described below, while arising at YIA, are also indicative of the experiences and growth reported by Fellows across all of our clubs.

The STEM Club at YIA is part of the *Technology Student Association (TSA)*, which is a national student organization that aims to foster "personal growth, leadership and opportunities in STEM" (Mission Statement, 2011) through sponsorship of middle and high school competitions. As denoted in Table 1, the CSC program is working with the TSA student chapters at LHS and YIA.

YIA is the International Baccalaureate (IB) school for its home school district, and all students are expected to adhere to the strict academic standards of the IB program. The school's diversity and high percentage of students on free and reduced lunch are reflective of demographics in the district. Recognized as standouts at their feeder schools, some YIA students excel and move on to top colleges after graduation. At the same time, a large proportion of the

students struggle with poverty and other challenges, which contribute to issues with engagement and completion of academic requirements.

Four STEM CLUSTERS undergraduate Fellows visited 8th and 10th grade technology classes at YIA for one 90-minute block each week to prepare for the TSA competition. Activities included circuit design using conductive ink pens, a technology-themed student debate, and a “60 minute maker challenge”, where students were given basic materials, a list of constraints, and asked to use their design skills to complete a simple task in limited time.

The unique contexts at YIA presented a challenge for the Fellows there: How best to engage a group of students, knowing that there may be difficulties in executing the steps and devoting the needed time to excel in the year-long TSA preparation process? Although the YIA TSA chapter did not send any competitors to the 2016 state tournament, the groundwork laid by the 2015 Fellows resulted in a healthy group of 15-20 competitors expected to compete in the 2017 TSA state tournament.

Young International Academy STEM Fellows

The following biographical descriptions of the 2015-16 YIA Fellows are informed by their biosketches, reflections, and interviews.

Karl is a second-year mechanical engineering major who came to study engineering due to his successes in mathematics through high school. In his application for the CSC program, he expressed great enthusiasm about the opportunity to work with students and share his love of STEM.

Sandra is in her second year of college after serving 4 years as a passive sonar technician in the U.S. Navy. A pre-bioengineering major, she was still exploring other options in STEM at the start of the program. In particular, she expressed possible interest in teaching mathematics after graduation, although she was more committed to her decision to study engineering by the end of her year in CSC.

Marcus is an electrical engineering major one year away from graduation. He is broadly interested in STEM and was a TSA participant in high school. He worked for 10 years as a firefighter until an injury forced his retirement, and he now works part-time as an emergency medical technician. Marcus speaks passionately about his desire to promote equity across STEM and was motivated to apply to the program by his young daughter. It is his hope that he can be part of a STEM community where she will have the same opportunities he has had.

Colleen is in the final year of her course of study double majoring in economics and psychology. She has extensive coursework in biology and served as the President of the university’s Biology Club where she had her first outreach experience through dissection demonstrations at local schools.

Shared Outcomes: Content Knowledge

To best attract a breadth of students, the YIA team designed their club to highlight ideas from across STEM. Sandra reported that, *“I am learning a lot more about different subjects and am enjoying it.”* Karl expressed how he benefitted from preparing to present such a large variety of topics: *“Every week we do something different. Whether it’s demos, or different projects, I always take something away from them. Whether it’s learning a small detail or just reinforcing topics I’ve learned, working with the students helps me better understand STEM.”*

Marcus related how preparing for students' detailed and insightful questions forced him to conceptualize content at a deeper level and sensitized him to the equal importance of generalized as well as detailed knowledge in STEM.

"How am I going to explain this to someone who hasn't had calculus? And it's that explaining, whether you want to call it translating or making it accessible or whatever, that's caused me to go back and learn more."

Sandra noted that she "spent quite a few hours" on preparatory research, and pointed out that her preparation time was beneficial, stating "By doing this research I end up learning a lot about the topic that I didn't know before." Colleen, the team's only non-engineer, had the opportunity to broaden her horizons through the TSA's focus on technology. As an example, she stated that "I don't know a single thing about circuitry... [Although] I do now, because I had to learn it to teach it."

Shared Outcomes: Communication Skills

Activity planning and interactions with students shaped Fellows' communication skills. Karl directly attributed this growth to his experiences with his club, and opined "This growth in communication skills is difficult to occur naturally because if you are not in a position where you have to teach others, it won't happen."

Fellows devised ways to explain complex topics to middle or high school students, which impacted their overall communication skills. Karl stated this most directly when he wrote, "Working with younger students every week and trying to convey science topics in order to spread the ideas that revolve around STEM was a bit challenging at times, but I was able to gain a lot from it"

Sandra often utilized an interesting two-stage process: after building her own content base, she would look to other resources as she prepared to communicate. "[After reviewing resources to support her own knowledge] I ended up taking notes of key points ... and then I went on to websites aimed at children to see how they attempted to teach the subject to younger students and found good examples that they could understand."

Colleen took the lead on a presentation and activity about DNA, which led to a number of deep and interesting questions from the club members. Reflecting on this process, she shared an opinion widely held by many Fellows – that communicating STEM should include an emphasis on revealing how content is applicable in the "real world". She states that "my definition of effective communication would be creating a working understanding of STEM concepts and how to apply them."

Significantly, we noticed an emerging motivation from Fellows to promote better STEM communication in our society, specifically breaking down the walls between the STEM community and the broader public. Marcus states

My colleagues tend to talk about "translating" when speaking with the public... We must not only translate, we must become more approachable.

Sandra, in recognizing the importance of sharing STEM with the public to build a sense of ownership states, *“If scientists and other professionals don’t communicate what they are doing, the public doesn’t get a say in anything that impacts them.”*

Shared Outcomes: Metacognition

Evidence of metacognitive growth was present across the YIA Fellows, arising both from their need to learn new knowledge to bring to their clubs, and their reflections and observations of how their students’ learning mirrored or otherwise influenced their own. For instance, Sandra explained how her efforts to find different sources of information for her club changed how she prepares for her own classes: *“I find that I learn a lot better by using all kinds of resources and not just by the lectures in class and the textbook.”* She also spoke about difficulties in her physics coursework and her struggles to grasp physics concepts. However, she reported in the fall that *“[Relating physics concepts to club students] ends up helping me in [physics] class to understand the equations and conceptual ideas”*, and that *“relating the physics concepts ... to everyday things actually helps me”*.

Marcus observed that he was processing material in his own classes differently, stating that *“Prior to joining the project, I read the text, took my class notes, and digested the material by summarizing the material. In short, I would ask myself: ‘how would I teach this to college students?’ Now, I ask myself ‘how would I teach this to my 10th graders?’”* This led him to an important conclusion about how he might support his own learning. *“I’ve found that trying to digest material prepared for questions that hit more at the basics of the topic is far better (for me at least) than trying to synthesize a topic at the ‘50,000 foot’ level that we, as college students, tend to do.”*

Karl summarized the importance of breaking down a problem sequentially. *“First off, you’ve got to think analytically. Think step by step, see how things work, and that’s the big thing about problem-solving. I think you need to have a strong base of content knowledge before you can approach problem solving.”* Both he and Marcus also highlighted the need for strong foundation of content knowledge to be effective at problem solving in STEM.

Identity as a Future STEM Professional

Feeling competent in the role of a STEM professional moves beyond cognitive attributes, such as content knowledge, to also having a set of skills and characteristics to learn and maneuver successfully in STEM. As a community of practice, the STEM club experience presented an opportunity for YIA Fellows to assess their views of STEM and their role as a future STEM professional.

A recurring theme across YIA Fellows was a view of STEM that is interdisciplinary, yet bounded by perceptions of self in relation to discipline-specific competencies. For Sandra, implementing physics-heavy activities proved especially challenging despite her broad view of STEM and the fact that she was concurrently taking her second undergraduate physics course. She describes this scenario during a demonstration on angular momentum using trebuchets.

I didn’t know anything about it and I didn’t feel comfortable teaching it. It turned out Marcus actually knew a whole lot, so he kind of took over.

In this case, Sandra not only relied on but also deferred to the expertise of her peers. This was a common occurrence across the YIA club and reflects the constraints and affordances of having a discipline-specific identity in STEM. Colleen describes her own competencies similarly in relation to the DNA activity: “*Since I’m the biologist, I chose to do a DNA extraction.*” Across multiple instances, Fellows’ self-identified their expertise and sense of belonging to one or more STEM disciplines. For Marcus, in his final year as an electrical engineering major, one particular experience, described in an interview, had a profound impact on his identity as an engineer.

[A quiet, reserved student] came up afterwards and asked what exactly a short circuit was... [T]o be able to translate that into something that he understood was probably the first time I’ve ever felt like an engineer.

Explorations of self in relation to experiences in different contexts are at the core of our understandings about identity. Karl describes his motivation to pursue a STEM career as a product of his ability to easily grasp math and science concepts at an early age, which led to his successes as a STEM learner in high school.

I believe I am successful in STEM because I have always done well in math and science. I always liked it so that was a big reason for me [to succeed and continue in STEM].

These early experiences of success contribute to Karl’s enjoyment of STEM and, ultimately, the view he holds of himself as a STEM professional.

Evidence of Shared Outcomes Across Other STEM Clubs

Evidence of growth and shared outcomes were present in across all clubs, as presented in Table 3.

Table 3. Additional Evidence of Shared Outcomes

School	Fellow	Quote
Gold Meadow High School (GMHS)	Delilah	“ <i>[W]e did a lot more experiments when students would sometimes have to reason a lot more through what they were doing and that sometimes you have to fail. This was important for the students to know as well as a good reminder for me.</i> ” (Metacognition)
	Nora	“ <i>Without CSC, I might not have brushed up on principals of chemistry and physics, nor would I have learnt some basic properties and tools at the disposal of engineering students and professionals.</i> ” (Content – General Knowledge)

Larimer High School (LHS)	Kelly	<i>"...you have to start with foundational things. You cannot assume the audience or the students know too much. Not everybody knows what everybody knows."</i> (Communication)
Eastern Leadership Academy (ELA)	Burt	<i>"By effectively communicating their work to the public, scientists (or mathematicians, engineers, etc.) can awaken within their audience the same appreciation of and curiosity toward the natural world, providing not only intellectual enrichment but a greater appreciation for the culture of discovery."</i> (Communication – Civic Responsibility)
	Allison	<i>"That's really what a lot of it is when you break it down. Engineering's trying to solve a problem, math's trying to solve a problem, biology's trying to figure out how nature solved a problem, technology's trying to make less problems... it all ties in there."</i> (Identity- Views of STEM)
Western Regional High School (WRHS)	Sharon	<i>"I think many people in the public have interest in learning about STEM but it may seem inaccessible to them due to the terminology that can be used. I think ... it's important to find ways to approach STEM communication in the least technical way."</i> (Communication – Civic Responsibility)
	Lorna	<i>"the fixes required during the build [of the hydrogen car] have exposed me to engineering techniques I have not yet encountered."</i> (Content – Disciplinary Skills)

Conclusions and Future Work

In our model, Fellows plan and implement activities in K-12 STEM clubs, participate in the STEMmunication seminar, receive support from faculty and peers, and reflect on their experiences and learning. We view these activities as 'essential elements' of our model as each contributes to the development of Fellows' content knowledge, metacognition, communication skills, and identities as future STEM professionals. A key finding from our group of participants is that outreach experiences can provide authentic learning experiences not only for K-12 students but also for them as the organizers of outreach activities.

Beyond the results described here in the context of the YIA TSA club, Fellows described a) the importance of collaborative work and effective communication in STEM, b) the need to be knowledgeable beyond compartmentalized areas of expertise, c) appreciation for the differences and similarities between STEM disciplines, and d) the need, as a STEM student and professional, to persevere through challenges. In short, participation in STEM clubs provided invaluable insights into the *realities* of STEM for these Fellows, bringing them closer to the professional world that they are about to enter.

Given our diverse cohort of Fellows, we are interested in further exploring how outreach experiences might encourage broader participation by undergraduates in STEM. We also believe that the Fellows give some interesting insights into the experiences, positive and negative, that are part of being an Undergraduate STEM major, and may inform our community's approach to campus- and classroom-based educational experiences.

In our future work, we plan to transfer the STEM clubs model to other outreach contexts to determine if the impacts observed through the clubs organized in 2015-17 can be replicated. Outreach models are often implemented without dissemination, and we look forward to discussions about how our model aligns with those of our colleagues across STEM education.

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