A Community Mentoring Model for STEM Undergraduate Research Experiences

Abstract

Undergraduate research experiences (UREs) in STEM disciplines operate predominantly under the traditional "apprenticeship" paradigm characterized by pairing an undergraduate student with a faculty mentor. However, scholarship on mentoring and emerging strategies for assimilating students into STEM communities of practice indicates that UREs would achieve more favorable outcomes and a *wider range* of desirable outcomes — especially among under-represented populations — using a model that deliberately incorporates *collaborative networks* or *constellations* of mentors. We describe a *community mentoring (CM)* model for undergraduate research experiences that avoids some of the common pitfalls of the traditional paradigm while harnessing the power of learning communities to provide young scholars a stimulating collaborative STEM research experience.   We discuss faculty and student reflections on a pilot community mentoring URE in astronomy conducted over four summers at our major state university.   Participant comments resoundingly implicate the team-oriented collaborative nature of the program as the most important feature of their summer. Given the anecdotal and research-based evidence supporting community mentoring, we advocate a wider adoption of the CM paradigm in undergraduate research experiences.

Introduction

Research-based classes or summer experiences have become a common element of the college undergraduate’s preparation. Some institutions have begun to require a research or capstone class as part of national initiatives to increase participation in authentic research projects for college students

(Boyer Commission, 1998; National Research Council, 1999; National Science Foundation, 2000). The benefits of undergraduate research experiences (UREs) appear to be numerous and well-documented, including increased interest in a discipline, elevated sense of self confidence and belonging in an academic or professional community, enhanced technical or communications skills, higher retention rates, stronger preparation for graduate study, and increased satisfaction with the student's undergraduate course of study (Bauer & Bennett, 2003; Lopatto, 2004; Syemour et al., 2004; Hunter et al., 2006; Russell et al., 2007; Russell, 2008; Sadler et al. 2010; Laursen et al., 2010; Eagan et al., 2013). There is evidence that underrepresented groups may benefit disproportionately from such experiences (Barlow & Villarejo, 2004; Kardash, Wallace, & Blockus, 2008; Laursen et al.,2010; Jones, Barlow & Vilarajo, 2010). The extent to which these benefits depend on the nature of the project, the duration of the research experience, the type and quality of mentoring received, and the demographics of the served population is still an active area of investigation (Russell et al., 2007; Russell, 2008 Bauer & Bennett, 2008; Lopatto et al. 2008; Chemers et al. 2011).

Most undergraduate research programs operate under the "apprenticeship model" which pairs a student *mentee* with an experienced scientist serving as the *mentor (i.e., the traditional model (TM);*, Nikolova Eddins & William, 1997). It is, *de facto*, the reigning paradigm for undergraduate research experiences although mentees may, in practice, interact with other undergraduates, graduate students, and postdocs in today's modern science laboratory environments. Nevertheless, shortcomings of TM mentoring in STEM fields are universally, if quietly, acknowledged: overworked faculty unable to make time for quality interactions with undergraduates; mentor travel plans leave mentees isolated and directionless; mismatches in mentor-mentee personality or expectations leave mentee isolated and directionless for a week or more; personality mismatches leave both mentor and mentee dissatisfied; inexperienced or disinterested mentors foist mentees upon an unprepared or unwilling graduate student or postdoc; mentors place mentees in high-risk projects doomed to frustration and failure; abusive behavior by mentor exploits student; immature or under-prepared mentees find themselves unable to meet mentor's expectations. Eby et al. (2000) developed a taxonomy covering 15 types of negative mentoring experiences that encompass the above list. These foibles motivate development of alternatives to the TM, because even well-intentioned, experienced mentors may unwittingly find themselves in a dysfunctional relationship.

Our purpose in this contribution is to describe and advocate wider use of a “community mentoring” (CM) model for STEM undergraduate research programs. Our CM model has similarities with the "tightly knit" research groups described by Feldman et al. (2013) and creates, by design, a science *community of practice* (e.g., Lave & Wenger, 1991; Wenger, 1999). We were sufficiently motivated by research on the benefits of CM that we implemented a CM model during our 10-week summer URE programs in astronomy from 2012-2015 at our major state university. This CM paradigm avoids or ameliorates many of the pitfalls of the TM while creating fertile terrain for entirely new beneficial outcomes to emerge. We discuss other identifiable advantages and shortcomings of CM based on faculty observations and mentee comments during our pilot program.

Community Mentoring in STEM Disciplines

The CM model for undergraduate research may be considered an extension of *learning communities* that have become endemic on college campuses because they demonstrably improve student success, especially for low-income and first-generation college students (Lenning et al., 2013; Visher et al., 2012; Zhao & Kuh, 2004). Research on mentoring underrepresented students, including women and domestic minority students concludes, "The notion of a single experienced faculty member being willing and able to play the all-inclusive role of mentor to a protege is wishful thinking," (Tierney & Bensimon, 1996). "A variety of individuals are required to help meet a mentee's diverse needs," (Chesler & Chesler, 2002). Ragins & Cotton (1999) argue for establishing mentoring pools to allow the diversity of mentee needs to be met by informal relationships with a community of mentors. They further conclude that formal one-on-one mentor relationships are less effective for female proteges — and by extension, other under-represented groups. Studies of mentoring for underrepresented & minority groups in the sciences reveal that these students seek out *multiple mentors* in their careers (Thomas, Willis, & Davis, 2007). Higgins & Kram (2001) argue for the supremacy of "developmental networks" over the traditional single-mentor model. "Constellations" of developmental relationships appear to produce higher levels of long-term career success and satisfaction than single-protege models (Higgins & Thomas, 2001; van Emmerick, 2004). Relationships where the protege has flexibility in selecting a mentor having similar values/attitudes/beliefs from among a community of mentors results in a higher level of satisfaction with the mentoring experience as reported by both the mentor and the protege (Thomas, 1990; Ragins & Cotton, 1999; Allen & Eby, 2003; Eby & Lockwood, 2004). Having a "mix of mentors" was found to be "mildly beneficial" to the experience of mentees across gender and racial lines (Russell 2008). In summary, our CM model is an attempt to bring more of these research-based "best practices" to STEM undergraduate research experiences.

Program Structure of a Community Mentoring Undergraduate Research Experience

The NSF-funded Research Experience for Undergraduates program in astronomy at our university has existed almost continuously since 1987. Beginning in the summer of 2012 and continuing through 2015 we replaced the traditional REU model that had been in place for nearly 25 years to implement a CM model. Six undergraduate students are selected each spring from a nationwide pool of >150 geographically diverse applicants to spend 10 weeks conducting research with the astronomy faculty using the university's 2.3-meter research telescope. Half of the participants are female. We preferentially select students with strong academic records but who have limited prior research experience at their institutions (82%); over our four CM summers the participants were 70% rising sophomores & juniors and 30% rising seniors.

Our summer program places the six students on a team as collaborators on a <u>single large research project</u> led by a <u>team</u> of 3-5 faculty assisted by 2-3 local graduate and undergraduate students. The project is designed to be sufficiently large that it cannot be accomplished without the resources of a team. One faculty member serves as the "science lead" who is responsible for setting the overall science program and research direction, including daily tasks and program goals. Other faculty play a variety of roles on the team. For example, one faculty member leads the nightly expeditions to the telescope, teaches telescope operation, data acquisition, and observatory safety. Another faculty member teaches daily classes on use of the linux computer system and scientific programming in Python or similar discipline-specific computer languages. Another faculty member leads workshops on the craft of digital data analysis using discipline-specific software for the reduction of astronomical data acquired by students at the observatory or extracted from public astronomical archives. Additional faculty roles include teaching seminars on authoring web pages, making scientific posters, writing scientific papers, giving talks, preparing for graduate school, science ethics, GRE preparation, and related professional development issues. Each year faculty roles rotate with a different person serving as the science lead.

Teams of 2-4 students use the observatory on a nightly basis (weather permitting), becoming increasingly confident and capable of operating a major scientific facility on a remote mountain at 9,700 feet elevation. After 4-5 weeks, they reach a level of competence where faculty supervision is no longer required. Students spend their afternoons working in a common departmental computer laboratory where they are immersed in a community of their peers from whom they can get feedback, advice, encouragement, and emotional support. Weekly community-oriented events include journal clubs where students read and discuss a common body of professional literature with faculty other students. Social events include cookouts at faculty homes, day hikes in the local area with members of the team, and weekend outings to national parks or national laboratories with members of the extended campus URE community numbering several dozen in a typical summer (e.g., in concert with chemistry, botany, engineering, and other departments). The summer concludes with oral presentations to the extended campus REU community.

Two major journal articles have been published from these summers (Kobulnicky et al. 2014; Dale et al. 2015), three more are in preparation, and over 20 conference posters have been presented at national professional meetings. Kobulnicky et al. (2014) determined that up to 70% of massive stars are formed within binary star systems, and that these likely produce many of nature's supernova and gamma-ray burst explosions. Dale et al. (2015) measured the history of star formation in the outer reaches of galaxies, finding support for an "inside-to-out" model of galaxy formation. An additional publication measuring the masses of black holes at the centers of spiral galaxies is being prepared.

Faculty Reflections

Our experience has convinced us that CM is a superior model for UREs. In no particular order, we summarize the strengths of the CM approach based on reflections from faculty who have served as mentors in both CM and traditional-model UREs.

- Students appear to thrive on playing a critical role in a major project as part of a team that initiates a project by collecting their own data; this is strikingly different than many UREs where students play a minor role in a project that is already underway using a dataset they are handed upon arrival.
- Faculty and students alike value the team approach to science. The CM model more closely emulates the operation of today's modern science teams that are increasingly large and highly collaborative by necessity. Students learn skills in data sharing, workplan management, and task coordination among team members. The team project approach helps build 21st century skills in communications and teamwork.
- Our CM model may help make STEM disciplines appear more accessible to students uncertain about their career path. Hunter et al. (2008) note that establishing collegial relationships with peers is an important outcome of UREs; peers provided an important network of support in the face of problems and engendered an essential sense of camaraderie. There is some evidence that under-represented groups show greater resilience when placed in a team setting. Kardash, Wallace, & Blockus (2008) report that 34.7% of female participants mentioned forming

collaborative relationships as the most satisfying part of their internship (versus 19.6% for men). Among the 23% of URE participants who reported *decreased* interest in a research career as a result of their summer program, one participant reflected: "…I like research, but I would rather work with people," (Kardash, Wallace, & Blockus, 2008). The CM model unambiguously communicates that science is a relational endeavor.

- Faculty and students appreciate that students are never left to flounder while a mentor goes away on travel because mentees are always immersed in a <u>team</u>.
- Kardash, Wallace, & Blockus (2008) find that sixteen percent of mentees report dissatisfaction with their mentor as the largest disappointment of their program. Awkward mentor-mentee matches are nearly non-existent in CM because students have an extended network of mentors; they can associate themselves with faculty with whom they might more closely identify.
- CM fully exploits the power of peer instruction (e.g., Crouch & Mazur, 2001) and peer mentoring (see sidebar). As members of a team who read the same literature and work on the same project, students have the opportunity to mentor each other. Possibilities include assisting each other with computer programming or data analysis, giving advice on career options, and sharing life experiences from their journey in science. An especially memorable example involves a graduate student unveiling the whole field of physics education research to an URE student over lunch. While not unique to CM, peer instruction is an inherent element that is more fully exploited under CM.
- Students report that they valued being trusted to conduct the full suite of activities required for success of the project: they collect data, they analyze it, they help prepare it for publication, and they present preliminary results at a professional conference. They see all the steps in the

scientific process. While most projects don't result in publications until 9-12 months after completion of the summer program, the students feel a sense of ownership and know that their role has been crucial to the team's success.

- A mixed-age cohort of undergrads and graduate students allows younger students to interact with members of their science community who are at more advanced career stages. Younger students garner first-hand accounts of life as a graduating senior or new graduate student. Younger undergraduates witness the performance of older students to understand what may fairly be expected of them.
- We have heard the criticism that our CM model deprives talented undergraduates from making unique contributions to a project. On the contrary, we have found that a large project creates space for each individual to define an area of specialty that gives an identity on the team. One student may have an interest in software development and, therefore, authors a specialized analysis code. Another may posses leadership qualities and become the coordinator of data and personnel efforts. In the CM model, team member roles are fluid and may be defined organically in accordance with the team's needs and with regard for each individual's abilities and interests.
- Faculty appreciated getting to participate in new subdisciplines, learning new literature and new tools over the course of their involvement. Faculty enjoyed having meaningful interactions with *multiple* students instead of just one.

Comments from participants on end-of-summer evaluations echo faculty observations (see sidebar for student responses answering "Which aspects of the program were most important to you?

Why?"). Of the 25 students in the CM REU over four summers, nine are in graduate school in a STEM field, seven are applying to STEM graduate programs, five are still undergraduates, three are science data analysts, and one is employed as an engineer.

" I loved working with my entire group instead of being isolated to different projects. This allowed us to help each other immensely and created a better group dynamic."

"It would have been no fun, and perhaps counter-productive to have someone breathing down our necks all the time. Additionally, it gave us a chance to figure things our for ourselves and learn from one another."

"The fact that the whole thing was done as team really made the whole thing more enjoyable. Not only did it help to bounce ideas off of them and get their input on problems that came up but we got close and now I have friends that will be there for a long time."

"The collaborative aspect of this project is fantastic. The ability to work with fellow students from different backgrounds and knowledge really expanded the boundaries of what I was able to glean from the entire program. Not only was I able to be helped by my coworkers (and now good friends), but I was able to help them out as well, solidifying what I knew and taught them, and learning more than I think I would if I constantly had to go ask the research advisor."

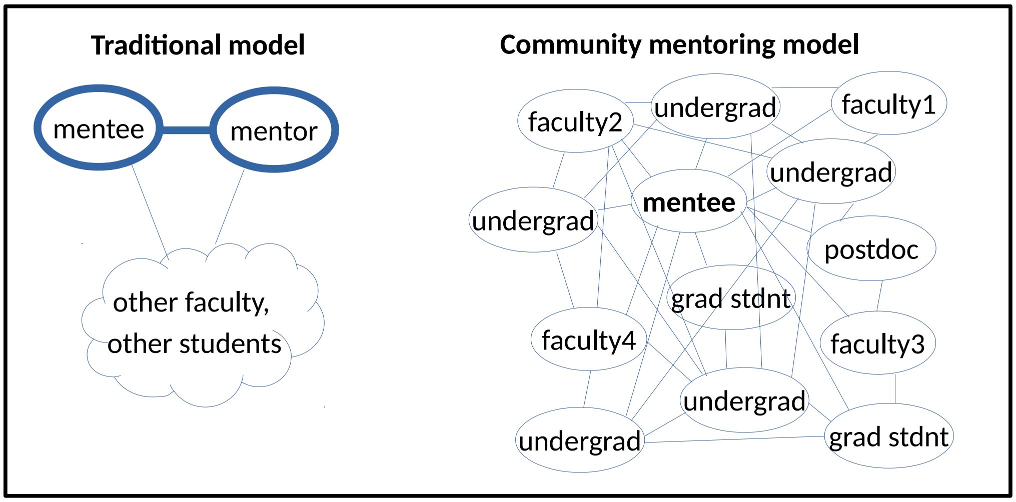
"I understand better how to work with differing personalities, and I learned how working as a team adds different challenges and benefits compared to working alone."

"The ability to work in such a tight-knit team is the most important aspect of the REU program for me. I believe we REU students are fortunate that we work together on a daily basis. We are able to work off of the strengths of each other in order to more effectively and efficiently solve problems, reduce data, and share ideas."

"... I ended up running a tutorial on spectral reductions and kind of teaching the other REU students. This experience was cool in that I was learning how to teach other students and at the same time I was learning the subject."

Figure 1 illustrates how we think of the differences between the TM and CM. In the TM a mentee interacts primarily with the mentor and perhaps peripherally with other members of the advisor's laboratory or local science community. In CM a mentee interacts, *by design*, with a network of science professionals at varying levels of intimacy dictated by the needs of the team and by a student's own interests and preferences. CM is not just throwing an undergraduate into a large lab filled with students and postdocs and expecting desired outcomes to emerge. It requires thoughtful crafting of the science program and the science team on a daily basis to achieve not only a publishable result but a vibrant community of science professionals. Feldman et al. (2013) conclude that participating in a tight knit research group helps undergraduates grow both methodologically and intellectually while they receive mentoring from multiple individuals.

Figure 1



Conclusions and Recommendations

While community mentoring may not prevent all negative mentoring experiences, an intentional CM model mitigates the severity of the common foibles. At best, CM immerses the mentee in a network of practitioners in an authentic 21st century scientific community of practice harnessing the power of peer mentoring, communications, teamwork, and community learning. There are no discernible drawbacks to CM that we can identify. *We suspect that the only factor that will limit the use of CM is the extent to which faculty are willing to be unselfishly collaborative.* While intellectual capital is sufficient motivation for some faculty, a small summer stipend may be required to ensure the active participation of others. We are not aware of other active CM UREs of this type. Colleagues at other universities express surprise when we describe our model. Given the burgeoning corpus of evidence supporting CM, we encourage directors of UREs to consider the benefits. Agencies that fund UREs should encourage—even require—these types of CM elements as essential components of UREs.

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