



Transitioning from Teaching to Mentoring: Supporting Students to Adopt Mentee Roles

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Abstract

Mentoring is an essential aspect of scientific research training across multiple academic career levels. In student research training contexts, mentoring is intertwined with expectations of increased autonomy and development of research confidence and independence. An often assumed premise of student research mentoring is that students are cognizant of the expectations of mentee-mentor interactions in research and that they are prepared to step into their new mentee role. This assumption is problematic in undergraduate research training where students may conceptualize their interactions with faculty based on student-teacher interactions they have become familiar with in their coursework. There is also indication that the present lack of structured training elements to help students navigate changing roles may especially impact underrepresented minorities in STEM education. Our contributions include reporting on the design and lessons learned from implementing a Teaching-to-Mentoring Framework comprising six professional development strategies in the context of a cohort-based research experience program. The framework aims to support this transitioning into adopting a new role, making the distinction between mentee-mentor and student-teacher interactions transparent, and enabling students to make the most of their undergraduate research experiences.

Keywords Teaching-to-mentoring framework · Teaching-to-mentoring evaluation · Undergraduate research training · Mentoring · Computer science

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Introduction

Mentoring is an essential aspect of research training across multiple academic career levels—undergraduate, graduate, postdoctoral, and junior faculty. In scientific research training contexts, student mentoring is intertwined with expectations of increased autonomy and development of research confidence and independence, and involves trust-building between mentors and mentees. Mentoring expands over student supervision and technical guidance in tasks by nurturing student familiarity with—and seeing oneself becoming a member of—a community of scientists (Childress et al. 2009). Efforts have been put into studying effective mentoring strategies (Shanahan et al. 2015; Baker et al. 2015; Tamer and Stout 2016), as well as high-performance mentors (Walkington et al. 2019), the impact of mentoring styles on how students develop their identities as scientists (Robnett et al. 2018), and mentoring among *near peers* including graduate-undergraduate mentoring (Revelo and Loui 2016) and incoming-advanced undergraduate mentoring (Zaniewski and Reinholz 2016). An online near-peer mentoring study with grade 9 and 10 mentees and university STEM student mentors recommended involving senior high school-level students as a midway link, and providing directions on role and activities prior to commencing mentoring interactions (Garcia-Melgar and Meyers 2020).

Yet, an often overlooked premise of scholarship on undergraduate scientific research mentoring is that protégés are cognizant of the expectations of mentor-mentee interaction and that they are prepared to step into their new role and adopt a research mentee mindset. This premise is especially problematic in undergraduate research training contexts where students are accustomed to conceptualizing their interactions with faculty as student-teacher interactions. Prior studies, for example, have reported reluctance in embracing research independence among undergraduate researchers, and a mismatch between student and faculty expectations (Lopatto 2003; Russell et al. 2007). In computer science, it is also possible that these challenges contribute to the disparities in representation of women and underrepresented groups in the research workforce (National Science Foundation 2019; Zweben and Bizot 2019), or at a minimum do not help address these systemic problems of underrepresentation. In this research brief reporting on an exploratory pilot study, we address two questions: (1) How can we design the provision of a structured Teaching-to-Mentoring Framework with strategies that aim to systematically aid undergraduate student researchers to transition from being taught in classes into being mentored on research? and (2) What do we learn from evaluating this framework from faculty and student perspectives?

Prior work highlights how mentored undergraduate research experiences can have positive outcomes for students (Rorrer et al. 2018). For example, the experience of moving from consumers of knowledge to producers of knowledge can empower students (Johann and Turbak 2001), cultivate self-identities as scientists, and stimulate their continuation into graduate school or STEM careers (Barker 2009; Estrada et al. 2018). More specifically in computing, motivating graduates to embark on research careers is challenged by the prospect of lucrative alternative professional pathways but, while there may be other factors, evidence from the Computing Research Association's Center for Evaluating the Research Pipeline (CERP) suggests a link between

undergraduate research experiences and applying to graduate school: 31% with such experiences applied to graduate programs while only 15% of students without it did (Wright 2020). More prominently, the CERP study shows that of those with a prior research experience who further enrolled into a graduate program, half entered PhD research education, which is almost twice as many as those who did not have such an opportunity (26%). Yet, students may already be inclined to enter graduate research training prior to their participation in undergraduate research experiences, and such inclinations or the students' academic grades might influence their career decisions.

A central theoretical underpinning for empirical work in the mentoring literature is the notion of *cognitive apprenticeship* (Collins et al. 1991) between a mentee and a mentor. This concept highlights the incremental journey-like experiences of learners, and thus also establishes a foundation for exploring the emergence of mentee roles. For example, “[a]pprentice-type relationships have particular value in engineering where we strive to help students develop as capable and creative problem solvers cognizant of broader social implications while they are still in an environment where the consequences of mistakes and failures are an increased opportunity for learning.” (p. 42) (Marra and Pangborn 2001). Our study places this theoretical notion in a computer science context, acknowledging that similar challenges apply to this STEM discipline as in engineering.

In addition, given the link associated between undergraduate research experiences and graduate school career choices, our study can also be framed from the perspective of Social Cognitive Career Theory (SCCT) (Lent et al. 1994). “SCCT posits that peoples’ career interests and intentions are shaped by their sense of self-efficacy (beliefs about one’s own capabilities and confidence) and outcome expectations (beliefs about the outcomes from particular choices), which stem from the interaction between various personal (e.g., disciplinary confidence) and socially mediated (e.g., mentoring) factors ... environmental supports and barriers play a role in individuals’ career decision-making processes.” (p. 8) (Gates et al. 2011). Recently, SCCT has been used to explore, from a critical gender perspective, how students decide on whether to pursue computer science degrees (Alshahrani et al. 2018). As a theoretical basis, SCCT integrates constructs such as *self-efficacy*, *interests*, and *performance*, and in this study such notions are relevant in evaluation.

The present lack of structured training elements to help students navigate changing roles from being taught to being mentored may especially impact underrepresented minorities in computer science and other STEM disciplines. For instance, a study of undergraduate research that focused on women participants and that also was typically successful in recruiting mostly female participants found that despite the female participants performing equally well in the program, afterwards, male participants had higher confidence in their achievements and capabilities (Kim et al. 2011). Also, a study found that Native American student participants rated their autonomy and academic resilience skills higher at the end of a STEM undergraduate research program if mentors had rated these skills high at start of the program (Griese et al. 2017).

Branchaw and colleagues covered a wide range of skills-building topics for undergraduate researchers, with topics arranged as curricula for 10 or 15 weeks to align

Teaching-to-Mentoring Framework (T2M)		
		
S1 Faculty Roundtable on Mentoring -- pre-program --	S2 Teaching-to-Mentoring Bridge -- initial program weeks --	S3 Graduate Fellowship Panel -- before program midpoint --
Objectives • Access and contribute to shared mentoring resources • Jointly envision innovative mentoring practices • Promote unified approach for addressing challenges	Objectives • Familiarize students with each faculty mentor's area of expertise • Highlight the diversity of faculty expertise and range of faculty research journeys	Objectives • Expose students to different funding models for graduate education • Highlight the role of grant writing in graduate education and beyond
		
S4 Cross-disciplinary Graduate Study Event -- around program midpoint --	S5 Mentoring Café -- after program midpoint --	S6 Team-based Mentoring Resources -- available throughout --
Objectives • Introduce students to graduate research in a range of STEM disciplines • Promote the value of engaging with research(ers) outside one's discipline • Learn about graduate school experiences and strategies to find advising support	Objectives • Inspire students through informal interactions with advanced graduate students • Educate students about the challenges of grad school • Discuss strategies for successful work-life balance	Objectives • Ensure access to resources for streamlining mentor-mentee interactions • Provide help for easing into managing research time and research deadlines
 The T2M framework (S1–S6) enhances research experiences on projects that use team-science principles with two peers and multiple mentors -- occurs concurrently with T2M --		

Fig. 1 The Teaching-to-Mentoring Framework with six strategies, S1–S6, was designed to engage complementary stakeholders (undergraduate researchers, faculty mentors, and near-peer graduate students) in a cohort-based undergraduate research experience program, structured around mentoring teams using team science principles. The framework aims to support student mentees' transition into research

with summer or semester research programs, respectively (Branchaw et al. 2019). In contrast, we focus explicitly on mentoring within a unified **Teaching-to-Mentoring (T2M) Framework**, illustrated in Fig. 1. The T2M framework is designed to fit within the professional development component that complements a 10-week intensive cohort-based undergraduate research experience with multiple mentors. The framework aims to support mentees in developing a *mindset toward research* (defined below) during their initial or early encounter with mentor-mentee relationships, so that students can make the most of their mentee-mentor experience.

Definition: *Adopting a research mentee mindset is characterized by the development of research skills such as taking initiative, contributing creative ideas, solving problems, taking ownership, seeking progress, progressing independently, engaging in thoughtful decision-making, and applying critical thinking. These skills can empower students to be motivated agents about their long-term research careers from the beginning, build confidence as researchers toward their personalized scientific identity, and cultivate human-centered role dynamics in mentee-mentor apprenticeship relationships.*

We hypothesize potentially important benefits if students transition promptly and without being hindered by unnecessary stress into a research mentee mindset. We specifically address this through the provision of carefully designed strategies (S1-S6 in Fig. 1) that integrate complementary stakeholders—undergraduate researchers, faculty mentors, and near-peer graduate students, in undergraduate research contexts. T2M aims to transparently transition undergraduate students into a new academic role, clarifying the distinction between mentee-mentor versus student-teacher interactions, as well as expectations for the former, for enabling students to make the most of their undergraduate research experiences. The T2M Framework further recognizes that there is a need to enable students to have early research experiences in computer science, to afford insights into whether graduate school is a career path of interest, including for students who are first-generation university students or from underrepresented minorities in computer science. The T2M strategies were deployed and evaluated within a summer Research Experiences for Undergraduates Site program at a private doctoral university, characterized by *high research activity*, in the USA. The program facilitated research experiences which involved pairs of undergraduate students being guided on a research project by faculty mentoring teams, thus using the principle of team science. The projects were organized around a computer science-focused intellectual research theme.

Marginalization and unconscious bias can impact the mentee experience in mentored undergraduate research. One study explained how faculty can rethink mentoring (including facing their own preconceptions): “[f]aculty are key players in the development of students ... diversity itself provides opportunities for both students and faculty to learn and to have an impact on one another” (p. 84) (Scisney-Matlock and Matlock 2001). Prior work shows that undergraduate research environments can function as “counterspaces” (p. 162) that affirm and develop students’ identity in STEM science, but that research environments can also be negative, unproductive spaces where students may even encounter microaggressive experiences such as race and gender bias, preventing equal entry into the intellectual research space (Lane

2016). The presented framework seeks to address the latter issues by having multiple mentors per project, as the team mentoring structure provides an increased level of accountability among mentors.¹ Thus, T2M aims to level the playing field and demystify mentoring. Our study focuses on undergraduate students and acknowledges that there are various layers of interactions and gatekeeping in mentoring situations that the students are required to navigate, including faculty mentors, near-peer mentors, and peer-to-peer mentors, and the framework was designed to enable this. The outcomes suggest that by centering on mentees' transition phase to a research mindset, mentees can be self-advocates with agency from the start of their experiences with conducting research.

Methods

To address the importance of easing students' transition from being taught by faculty instructors in classes to being mentored by faculty mentors on research where outcomes are less certain, our Teaching-to-Mentoring Framework is comprised of six programmatic strategies (S1–6), illustrated in Fig. 1. For each, we discuss its design.² Then, we introduce how we evaluated the framework's effectiveness with IRB-approved evaluation components using informed consent, and report on the participant demographics.

S1: Faculty Roundtable on Mentoring

Prior to the 10-week research program, a substantial portion of an annual faculty mentor retreat was dedicated to a *Faculty Roundtable on Mentoring*—a session for discussing mentoring and strategies for scaffolding students effectively into being mentored. For framing a rich discussion, the organizers provided an annotated bibliography summarizing the theoretical underpinnings on mentoring and highlighting key resources from the mentoring and STEM education research literature (Herman and Mandell 2004; Tamer and Stout 2016; Childress et al. 2009; Gates et al. 2011; Marra and Pangborn 2001; Scisney-Matlock and Matlock 2001; Healey and Jenkins 2010). Following a review of these materials, faculty mentors were given an opportunity to discuss creative applied strategies for mentoring undergraduate students and how to aid students' transitioning from being taught to being mentored. They could also share experiences and discuss mentoring challenges faced. In addition to promoting a unified approach to mentoring among the program's mentors, the roundtable discussion provided a space for alerting newer faculty mentors to some of challenges that they may encounter when mentoring undergraduates researchers.

¹ The program organizers are research-active faculty and also served as research mentors on the mentoring teams. While this may be a potential methodological limitation, it was also beneficial as it enabled contextualized, rich reflection on results. We recognize that this may not be possible in all settings.

² There were a few additional programmatic elements such as workshops or outreach to develop participant abilities.

Organizers emphasized to mentors that the students were not technicians and that the intent was for a genuine research experience with the students engaging in meaningful research contributions. Other agenda items for the faculty mentor retreat included a review of program structure, logistics, and expectations for faculty and students.

S2: Teaching-to-Mentoring Bridge

In the initial two weeks of the program, every faculty mentor gave a talk to the entire cohort of undergraduate students. Dubbed the *Teaching-to-Mentoring Bridge* series, mentors were invited to describe and discuss their own research journeys, and they introduced their primary area of research and described the types of problems they were working on. Thus, students could gain insights into how the work of members of the faculty team of mentors fit within the overall intellectual research theme of the program. In addition to highlighting the cultural and gender diversity of the mentors as well as providing examples of the wide range of pathways to an academic research career, the series of talks further exposed the students to areas of research and specific research problems that they may not have previously considered. A list of research talk topics in the series included:

1. Serving society with research
2. Facial expressions in virtual reality and affective computing
3. Big data and emerging journalism
4. Visual perception and what we learn from tracking the eyes
5. Assistive technologies
6. Intelligent systems that learn deeply
7. Human-centered AI for deaf and hard-of-hearing users
8. Linguistic sensing and computers making linguistic sense

S3: Graduate Fellowship Panel

During a three-part series of sessions focused on grant writing for graduate school, different funding models including graduate fellowship programs available from governmental and industrial sources were discussed. The organizers then arranged for the undergraduate students to interact with a panel of current and prior graduate fellowship awardees comprising doctoral students and faculty who attended face-to-face or remotely (Fig. 2b). The panelists shared their own experiences, what the fellowship award had meant for their graduate school careers, and tips for preparing successful applications. Panelists also made exemplar materials available to the student cohort in order to facilitate the discussion.

S4: Cross-disciplinary Graduate Study Event

Around the program mid-point, in collaboration with other local undergraduate research programs from a variety of disciplines, we arranged a symposium about graduate study and research (Fig. 2c). This event featured a formal welcome from university leadership, an invited faculty keynote address about a research topic and



Fig. 2 Three of the strategies deployed in the framework: **a** Mentoring Café: Pairs of undergraduate students interacted with advanced graduate students or newly minted PhDs. Using an academic speed-dating format, undergraduate student pairs rotated every few minutes, discussing with several graduate students in near-peer mentoring conversations. **b** Graduate Fellowship Panel session with current and prior recipients of graduate student fellowships, sign language interpreters, and student participants. **c** This cross-disciplinary symposium collaboratively organized across programs gathered undergraduate student researchers from a range of STEM disciplines to listen to graduate student presentations and panels about graduate school. Faces have been blurred in images to protect identities

introduction to the presenter's career path, invited broad-audience research talks by graduate students from different STEM disciplines to give insight into PhD-level STEM research and the value of interdisciplinary scholarly engagement, and two panels of PhD students discussing their experiences and providing reflective advice on finding an advisor or overcoming graduate school challenges, followed by a lunch allowing more informal interaction among students.

S5: Mentoring Café

Learning more about topics such as graduate school living, how to apply to graduate school, and social impacts of research are among the elements that can help stimulate interest in being a faculty member in computing for women and underrepresented students (Tamer and Stout 2016). The program offered a session with graduate student volunteers from a range of disciplines. Using an academic speed dating format, and with the provision of café-style refreshments in an informal atmosphere, pairs of undergraduate students rotated in speaking with invited graduate student volunteers in timed conversations about graduate skills and graduate school perspectives (Fig. 2a). Pairing (or possibly grouping) undergraduate students in this

manner accommodates situations where there were fewer graduate students and also encourages more lively dialogue. However, the peers were encouraged to not team up with their usual project peer but to pair up with another student. The Mentoring Café attempted to tap into near-peer mentoring benefits. A survey of near-peer mentoring work focused on medical education (in particular first-year medical students as mentees) revealed important effects such as coping with stress, support during students' transition into medical school, and professional or individual gain (Akinla et al. 2018). Near-peer mentoring benefits have also been observed specifically with underrepresented minorities in STEM research training contexts at the undergraduate level (Trujillo et al. 2015).

S6: Team-Based Mentoring Resources

One of the aims of the program was also to provide experience with team-based research with real-world problems that emphasize social good and impact. The core structure in the student research experience is the research project team guided by faculty research mentors and with two students per team. Students had a primary faculty mentor and secondary mentors. Teams generally met at least twice a week, and students had regular day-to-day interactions with the program coordinators. A part-time doctoral student assistant held technical office hours and responded to technical and methodological questions (or these were directly addressed by program organizers or faculty mentors).

During the entire 10-week experience, mentoring was facilitated by a set of interaction resources such as a program calendar listing cohort activities, deliverables, and team meetings, team email handles, team drives for systematic archiving, a social media presence to share media or reminders of activities, as well as collaborative video conference and authoring tools that facilitated remote post-program continuation of mentors-mentees interactions as well as follow-up online get-togethers for cohort continued networking.

Framework Evaluation

Our evaluation of these activities was based on targeted questions in interviews with students, student surveys and a focus group, as well as on faculty mentors' assessment of key skills related to menteeship, and a faculty post-program survey. We focus our analysis on questions of relevance to mentoring and mentee skills. Considering multiple evaluation forms allowed us to attend to student voices yet avoided the pitfalls associated with evaluation that only relies on one source of evidence (Linn et al. 2015) or on student self-reports (Shanahan et al. 2015) which are less reliable indicators of learning than faculty assessment (Griese et al. 2017). Thus, we considered different instruments and both faculty (mentors) and student (mentees) roles in the process of evaluating the application of the T2M Framework. Since the evaluation was cohort-based it did not involve a random sample. The instruments were:

1. **Faculty mentor reports:** Over the course of the program, on three occasions faculty mentors completed mentor feedback reports with structured assessment of

their individual undergraduate mentee's knowledge and skills. The reports were spaced out at approximately equal intervals. They were completed online and the feedback was personalized for each student. There were 33 questions addressing skills and a final overall performance rating, as well as three questions inviting open-ended feedback where mentors could indicate what students excelled at, where improvements were recommended, and other comments. All information was returned in digital form to the student to self-reflect on and students could but were not required to discuss their feedback. Table 1 lists the subset of relevant questions analyzed in this study. Several of the assessed research mentee skills also loosely associate with notions such as self-efficacy, scientific leadership, and attitude although there is no simple mapping or hierarchical taxonomy with subordinate (hyponym) and superordinate (hypernym) concepts.

2. **Faculty post-program survey:** The week after the program ended, faculty mentors completed a survey online about their students and their own experiences in the program. The survey was conducted and processed by a program-independent external evaluation team which preserved respondent anonymity. Since the faculty survey was administered post-program only, the results were analyzed using charts, proportions, and inspection of open-ended answers.
3. **Students entry/exit interviews:** We conducted individual self-reflective entry interviews with students in week 1 and exit interviews in week 10. In both structured interviews, the two organizers took notes. Subsequent analysis of the notes from these interviews qualitatively grouped themes and used discussion to arrive at consensus on themes.
4. **Student focus group:** Mid-program, the students participated in a cohort focus group. The focus group was organized and conducted in-person by a program-independent external evaluation team. The independent evaluation team also transcribed and conducted qualitative data analysis on the focus group data to extract themes. Their analysis was structured to ensure confidentiality and anonymity of the students.

Table 1 Subset of assessment statements in periodic faculty mentor reports

QID	Abbr. (Fig. 3)	Assessed skill statement on a five-point scale
Q5	Initiative	Takes initiative in research tasks beyond what is assigned
Q9	Critical thinker	Applies critical thinking in the research process
Q13	Creativity	Contributes own creative ideas to the project
Q15	Problem-solver	Is adept at problem-solving
Q25	Ownership	Takes ownership of the project
Q26	Progress	When the student “gets stuck,” she/he seeks paths forward by own initiative
Q31	Independent	Has the ability to make independent progress between mentor/team meetings
Q33	Decision-maker	Demonstrates thoughtfulness in making own decisions or seeking support ...
Q34	Overall	OVERALL RATING: Performance of the student meets or exceeds expectations

The statements focused on skills characterizing a research mentee mindset. Faculty mentors assessed individual student researchers over the course of the program on three occasions and results were shared with the students. With the exception of Q26 and Q34, assessment statements began with *The student*

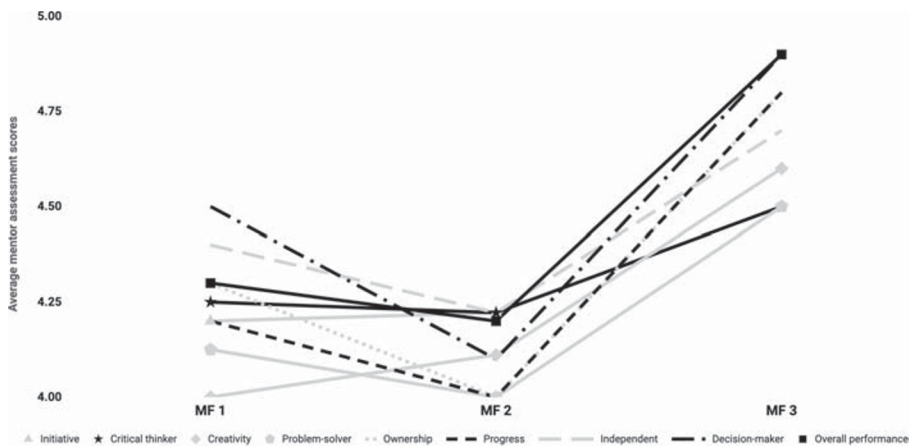


Fig. 3 Research skills displaying qualities associated with a research mentee mindset, assessed by faculty mentors over the course of the program in three mentor reports ($N = 10$). The trend is an increase from beginning to end of the program. Students were assessed by a mentor on the team; not by all mentors whom they interacted with. For each mentor report, the average cohort rating is provided. Infrequent missing values were excluded from the average

- 5. Students pre and post surveys:** At the beginning and end of the program students completed standardized surveys for US domestic computer science undergraduate research programs (Rorrer 2016). The surveys were conducted and processed independently, which preserved respondent anonymity. The results of pre and post questions on a 5-point Likert scale (with 5 corresponding to the most positive rating) mapped to theoretical constructs in the survey, and these were analyzed using descriptive statistics, the nonparametric Mann-Whitney U test, by computing effect sizes, and so on. To ensure reliability, we excluded Grit, the construct with the fewest construct items. Open-ended responses to additional questions on mentoring and the overall experience in the post survey were inspected qualitatively.

Participants

All 10 cohort participants were from the USA. All had a home institution other than the one offering the summer program, and 8 were computing majors (computer science or a computer science-related field). In addition, 7 attended institutions with limited access to research opportunities in computing, 5 were women, 4 came from years earlier than college junior (at time of application), 1 identified as African American, Latino/a American, or Native American (AALANA), 1 identified as experiencing a disability, and 2 included other underrepresented participants in computer science research.³ The 7 faculty research mentors represented distinct geographical

³ Applications to the program were solicited through the distribution of program information on email lists for computer science university educators and by reaching out to over 150 institutions in the USA with a recruitment email and flyer.

backgrounds and included 3 women and 4 men. All mentors were active researchers who regularly also mentor graduate students. Their primary responsibilities were the research projects. The following section introduces the result for instruments applied to faculty (mentor) and student (mentee) stakeholder groups, respectively.

Results

Faculty Instruments: Assessments of Mentee Skills and Post-program Survey

In Fig. 3, we provide the results on the mentor reports showing the temporal progression for the three assessments (each $N = 10$) from the subset of relevant assessment statements, listed in Table 1. The figure shows that two research skills associated with graduate mentees—*creativity* (Q13) and *initiative* (Q5)—increased across all reports, whereas three skills—*problem-solver* (Q15), *critical thinker* (Q9) and *independent* (Q31)—remained roughly flat (< 0.2 decrease), and other skills including *ownership* (Q25), *progress* (Q26), and *decision-maker* (Q33) clearly dipped, in the second mid-assessment. This could reflect that mentor expectations differed or that mentor expectations evolved as the program progressed and students gained more experience. It could also mirror that students worked through mid-program project challenges once they had passed the initial research phase and engaged more deeply with research obstacles in their projects. Overall, the trend was an increase from the first report to the third report reflecting the beginning versus end stages of the program.

Additionally, the post-program faculty survey responses confirmed that mentors were satisfied with their mentees and believed the research experience impacted students positively. All of the faculty mentors who responded to the survey ($N = 6$) *strongly agreed* that *the experience helped [their] students become better researchers*, and all but one *strongly agreed* that *their students were able to work on the project ... identified for [them] in the way ... envisioned*, that the program *[would] make [their] students more successful in graduate study*, and that they *plan[ned] to continue the work with [the] students towards publication*. (The other answer was *agree* for these three statements). Responses to open-ended questions also revealed that mentors felt that they benefited: “I gained a lot of experience working with undergraduates on research, and on mentoring in general. It was also very fulfilling to watch students get excited about research.” and “... [being a mentor] allowed me to work on a project that [is] expanding my own [on]going research and broaden my understanding of the subject matter.” Additionally, all faculty respondents ($N = 6$) answered *Yes* to whether co-mentoring with one or more colleagues worked well for them, reaffirming the team science mentoring structure from the perspective of the faculty mentors.

Student Instruments: Entry/Exit Interview, Pre/Post Survey, and Focus Group

The entry interviews elicited students’ thoughts on the current topic of interest based on this question: *What does being mentored and research independence mean to you?* The following abstract themes emerged:

- Mentors guide and do not micromanage (hands-off vs. hands-on)
- Students have agency and transition to independence
- Tap into experts' experience and prior mistakes
- Have regular mentor-mentee progress check-ins
- Mentors guide student path and help understand the field
- Being cognizant of mentee stage and awareness of knowledge gap
- Personal growth
- Not a taught step-wise process

At the exit interviews, we asked the following question: *How would you characterize your experience with building skills in being mentored by your research faculty?* Additional discussion in the interviews sometimes also touched upon mentoring. Student responses in the exit interviews tended to be more nuanced. This is not unexpected since students now had a research mentee experience to build their commentary on:

- Appreciation for interactions with graduate students (near peers) in events such as the Mentoring Café and the Cross-disciplinary Graduate Study Event, and in general for the exposure to graduate students
- Appreciation for independence in mentoring
- Discovery of enjoying the mentor-mentee relationship
- Enabled growth in skills and research interest
- Good to learn about both faculty research and their journey
- Discovery of challenges accompanying independence and steep learning curve, yet how this enabled skills growth

The appreciation for interacting with graduate student near peers was already apparent from other experiences commented on in the mid-program focus group. One student commented that a graduate student assistant “[was] helpful ... [and gave] very direct advice.” whereas comments also conveyed appreciation for access to research settings involving graduate students such as lab group meetings or reading groups; one comment noted that “[s]eeing what grad school would be like made it very appealing to me...”.

To the standardized student online post-survey, we requested the addition of a program-specific question asking respondents what enabled them to transition into research, without referring explicitly to the Teaching-to-Mentoring Framework: *Which two program components ... were most helpful for you to transition into being mentored on research?* The post-survey comments indicated students felt appropriately challenged and appreciated the independence offered in their team research projects and the chance to work through the whole research process. In addition, students appreciated the feedback from mentors and the interaction with near-peer graduate co-mentors. Quoting from the responses to this question:

- “Independent research and how to read research papers”
- “Statistical analysis workshop [and] Mentoring café”
- “The most important component was the independence we were given on the project. It was a bit overwhelming at first to have so much independence, but learning how to cope with this and take charge of the project independently is the

most important skill I learned and will help in my transition to graduate school. The second program component ... that was most helpful was [giving] many oral presentations ...”

- “Weekly meetings with mentors and documents like the weekly research plan and mentor emails which gave me a sense of what was expected of me”
- “1) Helpful, constructive feedback from knowledgeable mentors [and] 2) Tools and support from mentors/grad students”
- “Team discussions and program outreach activities”

A key theme in responses to the regular post-survey question *What was the most rewarding experience for you during the [research] project?* was about experiencing independence in research:

- “The most rewarding experience was independently designing my very own research project so that looking back now, my partner and I are able to take ownership of every part of our project. Learning how to work independently like this is the most valuable skill that I learned in preparing me for graduate school.”
- “... The heightened level of responsibility was great.”
- “Gaining more confidence in my research abilities.”
- “Seeing the work of the whole summer culminate in the achievement talk, poster presentation, and technical report.”

The mid-program focus group also provided early indication of the importance of having the opportunity to experience independence in research: “One of the biggest things is working independently. It’s a nice sort of transitional type of thing, you know, from school work where everything is sort of laid out and sort of structured. Then, this [is] way more in the direction of the independent work.” Another comment was that “I’ve been pretty satisfied with the amount of structure to the program. There’s not too much and not too little.”

However, independence does not relate to being alone. The appreciation for independence in combination with engaged mentoring was reflected in this comment from the mid-program focus group: “I appreciate the level of independence we have. It’s a nice balance. We structure our own days to an extent, but also, our mentor’s very aware of what’s happening and has very clear goals and suggestions for us.” Another comment also conveyed this point: “And I feel like there’s all this independence and everything, but it’s still pretty well structured in that you can still reach out to your mentors if you need support, if you need guidance.”

Additionally, Table 2 shows the statistical comparison of pre and post responses to questions thematically grouped into constructs in the standardized survey (Rorrer 2016). Both *Self-efficacy* and *Research skills and knowledge* self-ratings significantly differed for pre to post surveys with on average positive increase for responses. Also, the average self-estimation responses for questions in the survey’s section on *Scientific identity* and *Scientific leadership* showed a positively increasing trend, which indicated personal growth toward the scientist role, but was not statistically significant. However, *Intent toward graduate school* and *Attitude* self-ratings significantly changed with a decrease. The constructs’ directional tendencies of increase or decrease from pre to post survey are similar to national results for 2015, 2016, and 2017 (Rorrer et al. 2018; Raicu et al. 2018). A large effect size is observed for

Table 2 Results for mentee-related constructs for pre and post student surveys

Labels of constructs	Pre	Pre	Pre	Post	Post	Post	<i>p</i>	η^2	#c
	<i>M</i>	<i>SD</i>	α	<i>M</i>	<i>SD</i>	α			
Self-efficacy	3.4	0.65	0.74	4.52	0.46	0.84	.001	0.51	5
Intent toward grad. school	4	0.54	0.88	2.98	0.51	0.73	.001	0.51	9
Attitude	4.56	0.43	0.77	3.82	0.99	0.90	.043	0.23	5
Research skills/knowledge	3	0.84	0.77	4.10	0.67	0.87	.004	0.41	7
Scientific leadership	4.35	0.59	0.94	4.58	0.46	0.93	.436	0.04	8
Scientific identity	3.48	0.79	0.91	3.77	0.94	0.92	.739	0.01	6
Mentoring	NA	NA	NA	4.32	0.66	0.88	NA	NA	11
Satisfaction	NA	NA	NA	3.98	0.69	0.88	NA	NA	11

Surveys used 5-point Likert scales (where 1 indicates the most negative and 5 the most positive rating). Results are included for *means* and *standard deviations*, and *p* values for independent samples Mann-Whitney *U* test computed using SPSS, with corresponding effect sizes using $\eta^2 = \frac{Z^2}{N-1}$. Mentoring and Satisfaction were only included in the post survey. The number of survey items for a construct is provided in column #c. Cronbach's α results were ≥ 0.73 indicating that internal reliability was satisfactory. There were 10 student respondents. A missing value was excluded

Self-efficacy (positive) and *Intent toward graduate school* (negative), a medium-to-large effect size for *Research skills and knowledge* (positive), and a small-to-medium effect size for *Attitude* (negative) (Fritz et al. 2011).

Additionally, for *Mentoring* and (program) *Satisfaction* only post-measures were available, and the mean for *Mentoring* was high. In the post survey used (Rorrer 2016), students scored, for example, satisfaction with *[their] interaction with graduate students* (4.5, where 5 is *highly satisfied*) and *[their] faculty advisor* (4.2), whether the program *increase[d their] preparation for computing related graduate education* (4.2, where 5 is *strongly agree*) and *[their] interest in computing related graduate education* (3.5), and whether mentors' were *approachable* (4.7), *supportive and encouraging* (4.7), and *provided constructive and useful critiques of [their] work* (4.6).

Lastly, focus group comments on the Teaching-to-Mentoring Bridge series suggested the usefulness of gaining insight into the mentor role for developing identity as a researcher: "It's helpful to get to know mentors and see them in a position as a professor of something that you might want to do. You're not sure what you want to do, but just the steps that they took to get there and what going through grad school is like and where they went and how they chose their path. It's super helpful as we start to think about what we want to do." Another comment explained: "It was also nice to see [the mentors'] passion ... seeing that passion and them be excited, it's like, 'Man, maybe I could be that in the future.'"

Discussion

The results of complementary forms of evidence jointly suggest that six principles emerged as especially valuable from the Teaching-to-Mentoring Framework:

1. *Opportunities for research independence, experiences of taking the lead in a team setting, and initiative-taking, under guidance of experienced faculty research mentors*
2. *Nurturing the development of research abilities, confidence, and membership in the research community*
3. *Near-peer mentoring by current and recent graduate students in STEM fields*
4. *Learning both about mentors' research interests and their research journeys*
5. *Metacognitive engagement with mentoring and the mentee role*
6. *Cross-disciplinary STEM mentoring*

The initial four return to theoretical notions discussed such as apprenticeship, SCCT, and near-peer mentorship, supporting their value. The remaining two highlight the importance of having the opportunity to engage in thinking about mentoring (metacognitive engagement) and the importance of diverse STEM perspectives (cross-disciplinarity).

The strategies were operationalized in programmatic components such as our Mentoring Café, Graduate Fellowship Panel, a cross-disciplinary symposium, the Teaching-to-Mentoring Bridge series, and the team-science structure of projects, in addition to conversations about mentoring during the program orientation and in program evaluation. The benefits emerged through strategies that facilitate interaction between student researchers, near-peer mentors, and faculty mentors with the goal of performing joint activities which transmit both know-how about research as well as enables a research mentee mindset to grow in the individual. For example, the Mentoring Café and the cross-disciplinary symposium allowed graduate students to pass on and share their experiences about the research mentee role. Along with the Graduate Fellowship Panel, they gave practicable insight into mentor-mentee activities and support during graduate school. As another example, the Teaching-to-Mentoring Bridge provided an intellectual space for faculty mentors to convey their excitement about research and provide exemplars of research career development, facilitating formation of research identity, and modeling mentee pathways. The Teaching-to-Mentoring Bridge can also be a vehicle to spotlight career achievements of underrepresented faculty mentors, which can be beneficial for diverse students (Kricorian et al. 2020).

The student pre and post survey further indicated that the program accomplished research training of students from their own perspectives. In this context, research products are also a measure of achievement. An important outcome is that all mentees engaged in co-authored efforts with their mentors to disseminate publications post-program. Of these, 8 students had manuscripts accepted as lead authors with their mentoring teams and 2 prepared reporting for an undergraduate university bulletin. From a faculty mentor perspective, students' skills related to the research mentee role tended to increase over the program, while a post-program faculty survey pointed holistically to faculty satisfaction with mentees' growth and investment in the mentoring process.

A potential limitation is that the qualitative analysis of themes in responses to entry and exit interview questions involved subjectivity, and expanded work could examine interrater reliability. Nonetheless, the discussion about mentoring and the use of probing questions in the entry and exit interviews may have aided students in conceptualizing and stepping into the mentee role, pondering on this new role and

associated interactions, and thinking about mentoring from a direct, metacognitive perspective. Also, given the modest sample size, the reported statistical results should still be interpreted with caution. Moreover, a possible limitation for the mentor report analysis is that differences in mentors' interactions with students and mentors' interpretation of the rating scale could also influence the assessment scores. Additionally, for the Faculty Roundtable on Mentoring, while the discussion was interactive and insightful, a limitation is that we did not confirm whether faculty consulted the annotated bibliography further or spent time reviewing the selected literature in detail.

Regarding the negative student survey results for *Intent toward graduate school* and *Attitude*, students participating in the research experience ranged from freshman to rising seniors, many without prior research experience. Thus, it is expected that participation in the program would help to add clarity about what graduate school and research as a professional career choice is like. Indeed, in the entry interviews, a common response from students regarding their intent was that they were seeking clarity and experience to see what research is like. This could help determine if research careers were right for them. Similar insights have been previously reported. For example, an undergraduate research program in engineering did not find an increase in the number of students aiming for graduate school in their career paths, which they related to students who planned on pursuing graduate school applied to their program with that interest in the first place (Burkett et al. 2015). An undergraduate research experience can enable students "a more informed choice" (p. 181) regarding the pursuit of and options for graduate school (Hartmann 1990), as well as increase their level of readiness and incentive once in graduate study, and experiencing research can also benefit students who choose a professional path upon graduation as well.

Conclusions

We proposed a way to address the challenges facing undergraduate researchers new to a mentor-mentee roles who typically for the first time face the open-ended nature of research and associated uncertainty of outcomes. We designed a structured framework with multiple strategies which were deployed to support students as they transitioned into the mentee role, including a formal structure for the research experience through team-mentored research projects.

The strategies in the T2M framework are cost-effective and could be adapted to other research training settings. They require some time investment, such as preparing a program for a cross-disciplinary event or preparing a literature review for a faculty mentoring retreat. The strategies are also applicable to both research institutions and undergraduate-focused colleges, although adoption of all strategies will benefit from involving near-peer graduate student co-mentors. The involved graduate students could be from a local or regional partner university if the institution only enrolls undergraduate students.

Future work can further validate the findings from this pilot study and examine long-term implications. In particular, how is the mentee experience impacted when there is a continuation of undergraduate research experiences with other mentors in new mentor-mentee situations? Future work can also continue to refine our

framework and the evaluation process, including prolonged follow-up. An open question is whether the transition into the mentee role is facilitated by mentoring styles shown to benefit science identity development (Robnett et al. 2018). We are interested in exploring if T2M can help address disparities in representation among students choosing to continue on to graduate school in computer science and STEM. Also, prior literature points to a commitment to mentoring undergraduate researchers from faculty members who experienced being mentored themselves as undergraduates (Baker et al. 2015; Skorinko 2019), yet what exactly was helpful to support their own successful move into research careers remains to be explored. When mentees become research mentors themselves, does their early experience in a Teaching-to-Mentoring Framework continue to impact their view on mentoring and the quality and time investment of their own mentoring of undergraduate researchers? Thus, we plan to examine the benefits of cross-cohort dialogues and alumni engaging in long-term reflection about mentoring on a periodic basis, as their roles may change from mentee via near-peer mentor to faculty mentor.

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