The Graduate Student Role in Undergraduate Research Mentoring: A Systematic Literature Review

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Abstract

Background: Graduate students have an important role in undergraduate research. They are typically in a triad mentoring relationship, where they mentor the undergraduate and are mentored by their PI or faculty advisor. This type of mentoring relationship is either an open triad, where the PI does not engage with the undergraduate researcher, or a closed triad, where the undergraduate researcher has a mentoring relationship with both the graduate student and the PI. Through facilitating professional development workshops on undergraduate research mentoring with faculty and graduate students, the authors have found that existing mentoring relationship models do not fully describe the relationships between all three members of the mentoring triad. **Purpose:** This systematic literature review is intended to comprehensively explore the literature related to mentoring triads seeking to understand the graduate student's role in mentoring undergraduate researchers in order to support additional development of the models. **Methodology/Approach:** This study follows best practices in systematic literature reviews as described by Borrego, Foster, and Froyd in their 2014 paper: Systematic Literature Reviews in Engineering Education and Other Developing Interdisciplinary Fields. In particular, this study will evaluate the existing literature on undergraduate research mentoring relationships with graduate students. **Findings/Conclusions:** The initial database keyword search found 1208 articles. After applying various inclusion criteria, 63 articles were included in this systematic literature review. The findings of this study show the various ways that graduate student-undergraduate research mentoring relationships appear in the literature. Most literature supports the existing open/closed triad relationship model implicitly or explicitly (57%). **Implications:** This study examines articles that explore the relationships that graduate students engage in when acting as mentors for undergraduate researchers. In our current work, interactions with faculty and graduate students suggest that the existing models do not fully encompass the relationships they experience. The role of graduate students as well as the different experiences that postdoctoral researchers face in triadic mentoring relationships are avenues of potential future research.

Background

Quality mentorship provides a mutually beneficial experience, by which the undergraduate student grows personally, professionally, and technically and the mentor (graduate student and/or faculty member/PI) gains valuable assistance with their research. Undergraduate research mentoring can take on various forms, with varying levels of autonomy and control given to the graduate student. When a graduate student serves as a mentor to the undergraduate researcher, the mentoring is described as a triad between the faculty member, graduate student, and undergraduate researcher with the graduate student serving as the "bridge" or intercessor between the faculty member and researcher [1]. Sometimes faculty are very hands off, leaving the majority of decisions to the graduate student, such as the research topic, frequency of meeting, type guidance provided to the undergraduate. In other scenarios, the faculty member is much more involved, makes more of the decisions, and thus relies on the graduate student to serve more as the "messenger" or supervisor of the work assigned by the faculty member. In the

following sections we situate our study on the role of graduate students in undergraduate research mentoring by providing background context on undergraduate research mentoring and mentoring triads including an overview of typical research mentoring models, including triads, frequently described in the literature.

Undergraduate research mentoring. There are many forms of undergraduate research experiences (UREs) in which mentorship is provided. These categories include but are not limited to course-based undergraduate research (CUREs), NSF-funded research experiences for undergraduates (REUs), and extracurricular/personal research experiences. However, amidst variable circumstances, one of the true defining characteristics of these experiences is the availability of not only the faculty but of other mentor types as well. For example, an undergraduate researcher in a mentoring triad experience may go to the graduate student mentor instead of the faculty with questions or as their primary mentor. This could be due to the faculty not having enough time outside of a mandated meeting or the undergraduate researcher may feel a perceived power difference and would rather opt for a more peer-to-peer interaction. From a study by Sobieraj and Kajfez utilizing qualitative techniques to understand types of undergraduate research mentorship, this power difference can be seen in the following example: "It's a little intimidating when you don't know something to have to go to the advisor who, like, for sure knows the answer at least, like, whatever. Now there's a PhD student in my lab, on my project, so I felt much more comfortable asking him questions first before I brought it up to [my advisor" [2, p.7]. The previous example was also from a place of absence as the student did not have access to a PI or faculty member [2]. For the purposes of this paper, only the triad mentor type including the PI, graduate student or postdoctoral scholar, and undergraduate student will be mentioned but others do exist and serve different purposes.

One exploratory study by Mena and Schmitz delves into views of mentoring from the perspective of the graduate student mentor in a CURE [3]. In this study, one particular mentor described his role as purely "organizational and trying to set out a plan of action" [3, p. 5]. In describing the benefits gained from this experience, one other mentor said that they developed skills involving "trying to manage everyone's time and experience levels" [3, p. 5]. Another acknowledgment further said that the mentor usually had to make sure that they knew more than the undergraduate in order to help them with their work.

From the undergraduate research perspective, a mentored research experience will have the following steps. Firstly, an undergraduate researcher should usually expect a level of organization, especially in the case of the in-class or summer research experience. A plan of action will be put into place, whether at the beginning or at each subsequent meeting between mentee and mentor or the group of mentees and mentor. For example, in a paper comparing mentor/mentee perspectives in an REU, Annie, a sophomore Engineering student says, "In the first couple of meetings, we met and discussed our project goals, objectives, and we formulated a hypothesis for our research." [4, p. 4]. Of course, in the case of the extracurricular/personal experience, it should not be expected that a mentor will provide organization to the undergraduate researcher, but may advise a possible plan of action without further input afterwards. Secondly, the undergraduate researcher should be up front about their strengths/weaknesses and their time constraints. This allows the mentor to adequately allocate tasks that improve the skills of the undergraduate researcher without causing unnecessary stress. The undergraduate is also exposed to the idea of tailored timelines dependent on their own academic/personal circumstances in order to finish their side of the research within time. Thirdly,

the undergraduate researcher is expected to ask questions and clarify procedures/methods of analysis. The main point of mentorship is the exposure to differing ways of thinking. If the undergraduate is not questioning things, then they aren't thinking further and that will stagnate their ability to research. For example, Annie also details that she wanted her graduate mentor to be "supportive and willing to answer questions, even if she asked them already" [4, p. 4].

Mentoring triads. There are many different configurations of mentoring relationships that can be formed in undergraduate research. Some types of mentoring are dyadic, triadic, multiple, group-based, network-based, or hybrid mentoring styles [1]. The main configuration to be discussed in this paper is the triad. These take place between the undergraduate student, graduate student/postdoctoral researcher, and faculty advisor. Figure 1 shows there are two different types of triad configurations. Montgomery explains this as "There are two types of common triads – an open triad with the undergraduate having a connection to the postgraduate mentor and the postgraduate mentor separately being mentored by the faculty, but with little to no direct engagement between the undergraduate and faculty mentor, or closed triads in which each individual has a direct connection" [1, p. 4]. The graduate student is tasked with being the bridge between the undergraduate and faculty advisor. In an open triad, they are the only connection while in a closed triad, the faculty member also works with the undergraduate directly.

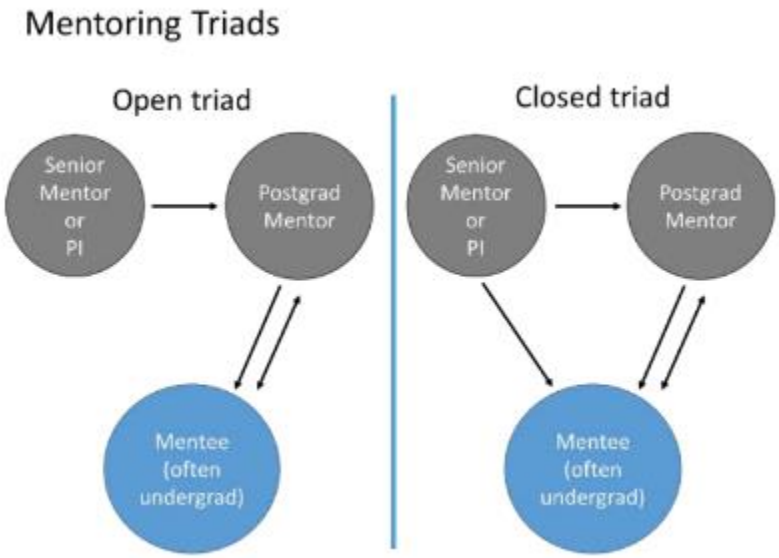

Figure 1. A model of both open and closed triads between the undergraduate, graduate/postdoctoral researcher, and faculty advisor. [1]

Graduate student role in undergraduate research mentoring. Graduate students play a crucial role in the success of undergraduate research programs. While faculty members typically coordinate their own research labs, they often delegate or share many research-related responsibilities with their graduate students, including mentoring undergraduate researchers [5, 6]. When graduate students provide undergraduate research mentoring, faculty have more time to address all their commitments, including research, teaching, grant writing, and service [5, 7]. Asking graduate students to share or lead undergraduate research mentoring increases the number of undergraduates who can be involved in research [8]. Graduate students may also

benefit technically and professionally from mentoring undergraduate researchers [5, 9], though experiences vary depending on the mentor training the grad student has received and their confidence in their ability to take on this role [5]. Graduate students who report positive mentoring experiences demonstrate greater productivity in their work and increased readiness for academic careers [5, 9, 10].

While graduate students mentor undergraduate researchers in technical, psychosocial, and career domains [6, 8, 11], they most frequently provide technical information and guidance to their mentees [6, 8]. As graduate students receive mentoring from their advisor, they learn essential research and mentoring skills to pass on to their mentees. Graduate students rarely receive formal mentor training; thus, they often learn by observing their mentor's style and abilities [5, 10]. Through a scaffolded process of taking on more significant and complex research tasks, graduate students gain skills to direct their independent research, thus making them an excellent technical resource for undergraduates. Undergraduate researchers often require more day-to-day guidance and input than graduate students, as they are novice researchers without much opportunity yet to practice their research skills [8]; another reason faculty members often ask graduate students to lead mentoring undergraduate researchers while they focus on other responsibilities, such as research, teaching, and mentoring graduate students.

Purpose and Motivation

This study emerged from work completed through a Kern Family Foundation grant focusing on improving undergraduate research experiences. As part of this improvement project, Rynearson and Pantoja have developed and facilitated workshops for faculty and graduate students related to undergraduate research mentoring. Through these workshops, questions regarding the graduate student role in undergraduate research mentoring were raised by faculty and students alike. Recognizing the role of a graduate student as a middle mentor or bridge mentor in the triad mentoring relationship, we found that there was not a lot of literature that spoke to the unique concerns and needs of this role. In addition, the mentoring triad models did not truly encompass the realities of the triad mentoring relationships for the STEM faculty and graduate students we worked with. To provide better structures and support for graduate students who are in this middle mentor role, we are delving into the literature to understand the state of publications related to graduate students in mentoring triads. Our work is guided by the following question: What is the extent of the literature regarding mentoring triads that include faculty, graduate students, and undergraduate students in undergraduate research contexts?

Methodology

To thoroughly review the available literature and understand the state of research on mentoring triads that include faculty, graduate students, and undergraduate students in undergraduate research contexts, we have chosen to use a systematic literature review. This defines our method and our methodology, the way we are approaching our topic. It is not enough to do a basic literature review; we want to be sure that we are broadly and systematically reviewing what is available with regard to graduate students in mentoring triads.

Systematic literature review. As defined by Borrego and colleagues' 2014 study on the subject, a systematic literature review follows a set of procedures in order to be reproducible [12]. These procedures are Decision, Identification of Scope and Research Questions, Inclusion Criteria, Finding Sources, Critique of Sources, Synthesis, Limitations/Concerns, and further writing the

review itself. The Decision stage is the first step, in which the researcher(s) must agree to be consistent and effective "between goals, research questions, selection criteria, and synthesis approaches." [12, p. 51]. The next stage, Identification of Scope and Research Questions, defines the question that is being asked and the places you will search for an answer. If this question is not articulated correctly, it may cause disastrous consequences later during all further stages, especially the Inclusion Criteria. The researcher(s) must pose a well-defined question for the study to produce a meaningful result. The Inclusion Criteria and Finding Sources section is defined below in a separate section. The Critique of Sources is used to assess the usefulness of each study gleaned by the Inclusion Criteria and Finding Sources. However, as a side note, this critique may reveal that the inclusion criteria is not adequate and was either too narrow or too broad. Further, it may also reveal inconsistencies in the Identification of Scope and Research Questions. The Synthesis stage allows the researcher to examine the sources acquired and reach a result that will either confirm or deny the original research question. This process may also identify other questions that our understanding of the material may not be able to answer. This stage may also be the most vulnerable to bias and/or going towards a desired result. The final stage of the review is the confession of Limitations/Concerns. These limitations may include the time spent synthesizing, the number of articles found from the bunch, or even the consistency of the review.

Researchers and roles. The research team comprised four people: one faculty advisor, one postdoctoral scholar, and two senior undergraduate students. All members of the team contributed equally to the search, selection, coding, and analysis. All four members wrote components of and edited this paper. Before beginning the systematic review, all members had engaged in some level of literature review so had some familiarity with the content.

Inclusion criteria and search strategy. For a method on how to collect possible articles/papers for analysis and discussion, three common inclusion strategies are done in order [12]. These strategies are defined by Borrego and colleagues in the section "Defining Inclusion Criteria" [12]. The first strategy is the selection of the database you will be searching within. For example, the researcher(s) may only search within ASEE PEER and Google Scholar, but not any other database. This diminishes the amount of duplicate articles. The second strategy is the use of Boolean operators such as AND/OR and specific keywords to diminish or broaden search results. This strategy allows for a more detailed analysis of the articles being given without having to sift through a mountainous amount of these articles. However, depending on the database used, a Boolean operator is not as reliable due to inconsistencies in the proper usage of AND, OR, and apostrophes. The third strategy is the use of a filter to sift through the culminated articles/papers to acquire articles/papers that would be useful to the analysis or discussion at hand. For example, after we used the first and second strategies, we narrowed down the articles/papers by using a list of ideas and keywords we wanted to be present in their text. For example, we wanted these articles/papers to include concepts such as "mentor," "graduate student," "undergraduate," "triad," and others as seen in the following section, Selection.

In the case of the first and second strategies, the topic of mentoring relationships in STEM disciplines is a universal educational research topic that has publications in disciplines other than Engineering describing the relationships seen in their laboratories, educational articles discussing the educational outcomes of mentoring relationships, or even behavioral science fields discussing the mentoring relationships more directly. Eight databases spanning STEM fields, educational and behavioral sciences, and general databases, were originally chosen as seen in Table 1.

Google Scholar provided too many results that did not appear to be related to the goals of the project, so was discarded as a possible database. Now, as there is a large amount of research on the subject, the second strategy must be utilized in order to narrow down the broad clump into a set of articles that can be sifted and analyzed. The keywords that were used to find papers are shown in Table 2. Even then, the third strategy, as seen below in Selection, is used in order to not only narrow but produce an effective and meaningful review of what is currently being researched.

Table 1. Databases chosen.

Database	**Rationale**	**Count**
Scopus	Abstract and citation database that includes a wide range of science and education sources	184
OneSearch	Integrated university library search	186
Google Scholar	Large-scale academic database	26750
ERIC	Education-focused database	147
PsychInfo	Behavioral and social science database	15
Academic Search Complete	Full-text database that includes open-access content	57
ASEE PEER	Repository for American Society for Engineering Education conference articles	1409
IEEE Xplore - Frontiers in Education	Repository for Frontiers in Education conference articles	109

Table 2. Keywords and resulting paper count from database search.

Keyword	**Count**
"mentor* triad" AND "graduate student"	60
"mentor* triad"	126
mentor* AND "undergraduate research" AND "graduate student"	1260
mentor* AND relationship AND "undergraduate research" AND "graduate student"	661

Selection. When making the selection of what articles to include in the paper there was a series of questions that were asked. All articles were put into Google Sheets and divided evenly between the research team. The team then read the abstracts and then answered the following questions shown in Table 3. The questions were broken up into categories, namely, triad

discussion, relationship, context, media, and whether the paper should be kept or not. Under Triad Discussion the goal was to understand if the paper at hand was about mentor triad or whether it was used as a surface level descriptor in the paper. The Relationship category was used to determine if the paper discussed relationships between graduates, undergraduates, and faculty. The third question asked was in what context the research was conducted such as a strictly undergraduate researcher, other, or none. The type of media was also collected on whether the paper was published in a journal, conference, or other type of publication. The final question asked was whether or not the paper should be kept in the article or not. If the researcher was unsure of what to decide there was a discussion option. All four researchers would then later discuss the particular paper on whether to include it or not.

Table 3. Inclusion criteria for abstracts and articles.

Triad Discussion	**Relationship**	**Context**	**Media**	**Keep?**
About Mentor Triad	Graduate/UG/Faculty	UG Research	Journal	Yes
Uses term mentor triad, surface level descriptor	"Near peer" (i.e. student to student)	Other/None	Conference	No
Other/None	Other/None		Other	Discuss

Assessing the quality of included articles is an important, but often overlooked step in systematic reviews [13]. In this systematic review on mentoring triads, we include all articles (qualitative, quantitative, and mixed methods studies) that meet the inclusion criteria outlined above. Given that we have considered all types of research studies for inclusion in our review, there is not one standard measure of the quality of these articles. In general validity and reliability are of concern, however, the measures of quality are different depending on the type of research. These include measures of reliability and validity, and procedures that limit bias for quantitative and mixed studies [14], whereas measures such as trustworthiness, credibility, and rich rigor are better measures to ensure the included qualitative studies are high quality [15, 16]. Screening criteria we considered in all types of studies to ensure poor quality studies were discarded were: 1) Are methods detailed enough? and 2) Are potential study limitations discussed?

After the initial steps of searching databases with chosen keywords, reviewing abstracts for basic inclusion, and reviewing full papers for inclusion criteria and quality, sixty-three papers were selected as the final set of articles. The breakdown of the number of papers that were first collected to the number of papers that were chosen and from what database are included in Figure 2.

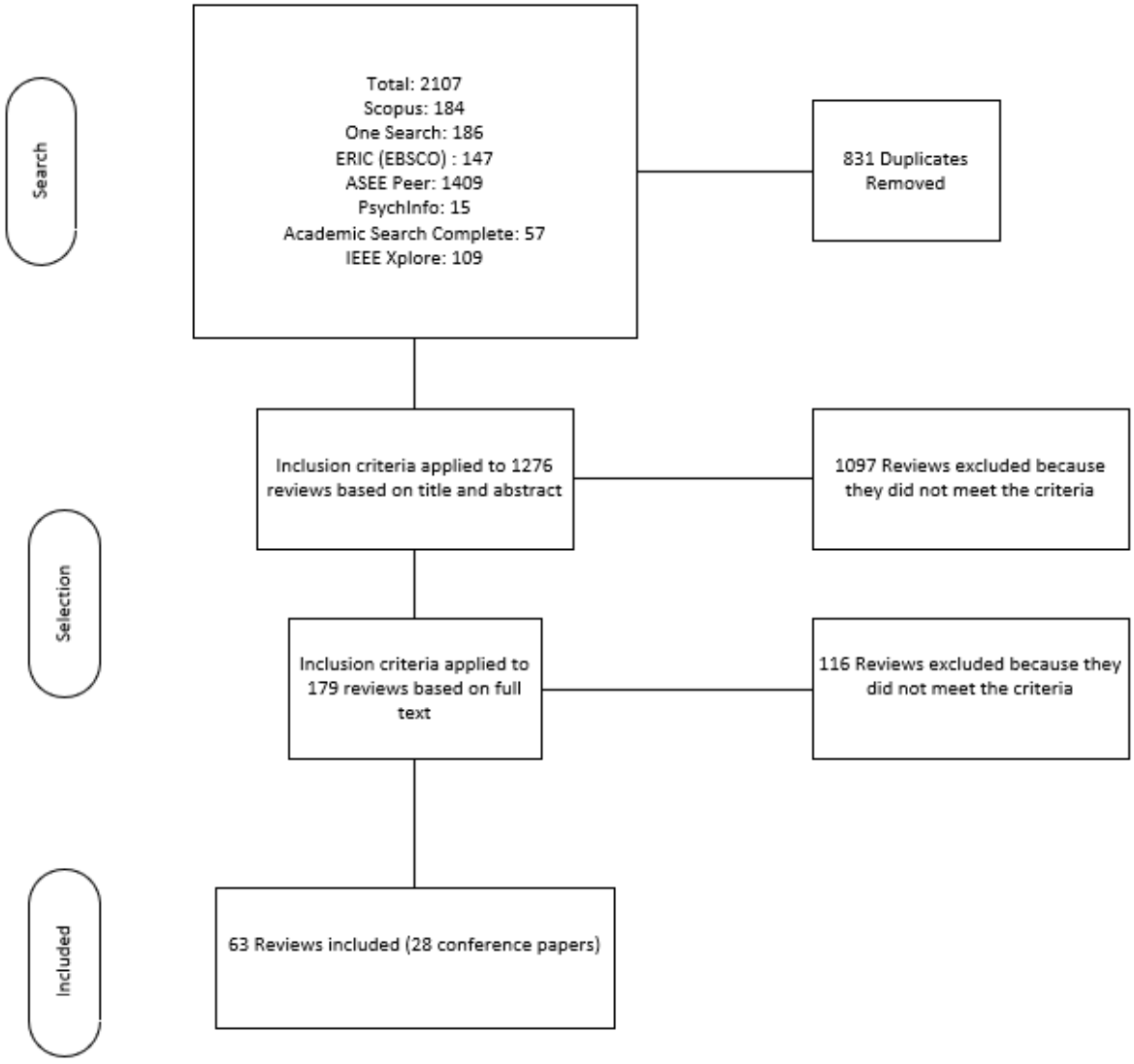

Figure 2. Overview of the number of papers for the search, selection, and inclusion. [11]

Coding. After the broad search, initial selection based on the abstract and full paper review, and screening for quality have been completed, each remaining paper was coded by two researchers, one undergraduate, and one senior team member. Coders were the team members who did not read the full article for prior screening purposes to reduce prior assumptions and bias from familiarity with the article. To answer the research questions, four main topics with non-overlapping codes were deductively developed from our initial literature review and research focus. These can be seen in Table 4.

Table 4. Codebook

Type of Triad	**Participant Focus**	**Study Focus**	**Power Dynamics**
Open-Explicit	Undergraduate	Mentoring Relationship	Described-Explicit
Open-Implicit	Faculty	Research Productivity	Described-Implicit

Closed-Explicit	Graduate Student	Undergraduate Outcomes	Not Described
Closed-Implicit	UG-F	Graduate Outcomes	
Other	UG-GS	Program Evaluation	
Multiple Triads, Explicit	GS-F	Other	
	All		
	Other		

Inductive codes are added to the final codebook if themes of interest emerged during the coding process. Multiple Triads, Explicit was the only code added and no additional categories were added. This paper focuses on the Type of Triad and Participant Focus categories for analysis.

Results

Search and selection. We first found all possible articles within our search parameters and removed all duplicates, going from 2107 articles across seven databases to 1276 articles. Two separate stages were used to determine which articles to include. The first inclusion stage ensured that the title and abstracts of the paper were within our field of study and were adequate to this systematic search, resulting in 179 articles. The second inclusion stage was more detailed and involved reading the entire paper to determine its viability towards answering the research questions that we had set out to answer. Sixty-three articles remained for our final selection.

As an additional note, we performed an informal check similar to snowball sampling, where additional papers may be found through the references of papers of interest [13]. As citations of interest appeared in the full papers during coding, we would look up the papers to see if there were others that should have been included in our search. All articles were already included within our search, leading us to believe that we have completed a comprehensive systematic literature review of graduate students engaged in undergraduate research experiences.

Coding. Each paper has been coded into one of the categories noted in each topic of interest. The codes are non-overlapping, so no paper is in two categories for any code and the sum of the code count for each topic is the total number of papers.

Type of triad. While some papers used the formal description of mentor triads, some papers very clearly describe either open or closed triads and do not use these terms. Therefore, we coded whether the triads were explicitly stated or if we have determined that they are discussing open or closed triads based on the descriptions in the paper. This gives us an additional lens on whether references to mentoring literature, in particular mentor models, are commonly found in studies describing mentoring triads. Code counts and examples from the articles are found in Table 5.

Table 5. Type of triad analysis

Code	Count	Example
Open-Explicit	0	N/A
Open-Implicit	5	"consisting of the faculty advisor, a graduate student from the laboratory, and the undergraduate they had been asked to mentor." [18, p. 2566]

Closed-Explicit	2	"supervisory relationship is triadic in nature, involving direct and indirect interactions between a faculty member, grad. students, and UG research assistants..." [19, p. 77]
Closed-Implicit	21	“The meetings were also attended by the program directors, faculty and graduate students mentors, and graduate student coordinator.” [20, p. 15]
Other	27	"To ensure a cohesive research experience undergraduate students are provided graduate mentors that are advisees of the faculty sponsor whenever possible. In instances when the faculty member advises no minority students for selection as graduate mentors, the mentors are selected from a group of volunteers from the graduate minority student body located at the institution." [21, p. 3]
Multiple Triads, Explicit	8	"These results suggest that an undergraduate research experience that incorporates multiple mentors at various career stages, like a faculty-postgraduate-undergraduate triad, may provide undergraduate students with a more complete mentorship experience" [22, p. 276]

Participant. The Participant topic included all possible permutations of the relationships in the mentoring triad, including focusing on a single participant’s experience, two of the three participants, or all three members of the mentoring triad. This analysis allows us to understand the state of the literature regarding triad mentoring relationships that include faculty, undergraduate, and graduate students, in particular, who is being studied. This will also allow us to focus on those articles that are primarily interested in the experience of the graduate student, our population of interest. Postdoctoral scholars were coded with graduate students as the reviewed articles used these terms interchangeably and did not differentiate findings across these participant groups. Furthermore, in the included studies postdoctoral scholars served in mentoring roles similar to graduate students. Code counts and examples from the articles are found in Table 6.

Table 6. Participant analysis

Code	**Count**	**Example**
Undergraduate	21	"The dependent variables (outputs) Student gains" [23, p. 1034]
Faculty	0	N/A
Graduate Student/ Postdoctoral Scholar	8	"The overall goal of this research was to better understand mentoring opportunities for postdoctoral scholars and graduate students." [24, p. 5]
UG-F	2	“Faculty members often have multiple roles in the development of undergraduate science students, including being course instructors, serving as academic advisors, and mentoring their undergraduate students in research experiences.” [22, p. 273]
UG-GS	15	"To ensure a cohesive research experience undergraduate students are provided graduate mentors that are advisees of the faculty sponsor whenever possible." [21, p. 2]
GS-F	0	N/A
All	11	"Each REU participant was assigned a research project, a faculty

		advisor, and a graduate student mentor." [17, p. 1]
Other	6	“For these reasons, we use the term “research advisor” throughout this paper instead of the more common “mentor.” This term applies to all individuals who engage with undergraduate researchers, including faculty, graduate students, postdocs, and technicians, who guide and train undergraduate research students” [25, p. 3]

Discussion

After coding these studies, our research team found that the triadic nature of the mentoring relationships between undergraduate student, graduate student (or postdoctoral scholar), and the faculty/PI overseeing the project is often considered, described explicitly in 10 articles (16%) and implicitly in a further 26 articles (41%). 8 articles (13%) focused on multiple types of triads. In the remaining 27 articles (43%), most considered dyadic relationships, either the faculty/PI and graduate student, the graduate student and the undergraduate student, or did not differentiate between the faculty and graduate student as mentor or undergraduate student and graduate student as mentee. A number of articles also described graduate students in a combined teaching assistant and mentoring role in a course-based undergraduate research experience (CURE). Some of the articles described a triadic relationship between the graduate student TAs and faculty PIs overseeing the undergraduate’s research project. Most of these studies were interested in the outcomes of the undergraduate students involved in the project, collecting data from the undergraduates only (33% or 21 articles) or incorporating supporting evidence from the faculty or graduate student mentors in addition to the undergraduates (78% or 49 articles). A few articles focused on the graduate students, with 13% (8 articles) collecting data from the graduate students only. No articles were strictly from the faculty perspective. One article (2%) did not include human subject data.

Overwhelmingly, articles that discuss undergraduate research experiences and discuss graduate students as mentors do not adequately describe or consider the triadic nature of mentoring common to undergraduate research experiences. Unsurprisingly, most articles relating to undergraduate research experiences focus on the outcomes of the undergraduates. The results of this systematic literature review show that there are few articles that explicitly consider the graduate student’s role in undergraduate research experiences and rarely explore the unique role they play as a bridge between faculty PIs and undergraduate researchers.

Limitations/Concerns

We have found some potential limitations that arose during our review of available published literature. One concern that surfaced during the early reviews was a fear that our selected keywords did not encompass all of the useful publications in the database. Beyond limiting our language to English publications only, different cultures may use different words to describe similar concepts or positions. It is possible that the second step in our Inclusion Criteria was too limited culturally to get a true systematic review of available literature. Focusing on STEM may have caused some relevant literature related to triadic mentoring relationships, particularly in the fields of nursing and teaching, to be missed in the search for literature. There may also have been relevant conferences that were not reviewed, such as international engineering education organizations or STEM disciplinary conferences, due to time constraints. There may also have

been articles in relevant journals that were not indexed in the databases included in this search. We chose a large number of databases to minimize this risk. We also checked relevant citations found in the articles during the full paper review to see if these articles were missing from our study. All articles reviewed were already included in the study, leading us to believe that we have a strongly comprehensive sample of articles related to graduate students engaged in undergraduate research mentoring. As authors, we may have also had some bias as we began to explore this topic after being unable to find papers describing mentoring relationships in the way we expected them to rather than coming to this study with no preconceptions regarding the data we were about to review.

Conclusions

Graduate students often play an integral role in undergraduate research experiences. They often act as a primary mentor, working closely with their undergraduate mentees, however they also report to their advisors, taking on a mentee role in a mentoring triad. This systematic literature review was undertaken to explore the state of the literature on the graduate students role in undergraduate research mentoring experiences. Journal articles and conference proceedings were included in the initial database search, resulting in 2108 articles from seven databases. After removing duplicate and removing articles that did not include graduate students in undergraduate research experiences, 63 articles remained and can be seen in Appendix A. After coding these studies, our research team found that the triadic nature of the mentoring relationships between undergraduate student, graduate student (or postdoctoral scholar), and the faculty PI overseeing the project is not always considered, with 43% of articles ignoring the full mentoring triad relationship in the undergraduate research experience. Only 16% used the term triad to describe the mentoring relationship. The open and closed triad mentoring models were first published by Aikens in 2016 [6], after many of the articles included in this study, and so those articles that described a triadic relationship were coded as implicitly describing the triad (41%). While having a model and a name allows for a common way of discussing a phenomenon, the nature of the relationships have not changed. In addition, while many of the articles include data from graduate students (34 (54%)), only 8 (13%) focused strictly on graduate students. To improve our understanding of undergraduate research experiences and the graduate student role in them, more studies need to be done focusing on the unique role of the graduate student as bridge mentor within a mentoring triad. A better understanding of the role of graduate students as bridge mentors can lead to better preparation for undergraduate research experiences and therefore better outcomes for all stakeholders.

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Appendix A: Papers included in the systematic review

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