

Research Anxiety Predicts Undergraduates' Intentions to Pursue Scientific Research Careers

Katelyn M. Cooper,^{1*} Sarah L. Eddy,² and Sara E. Brownell¹

¹Research for Inclusive STEM Education Center, School of Life Sciences, Arizona State University, Tempe, AZ 85281; ²Department of Biology, Florida International University, Miami, FL 33199

ABSTRACT

Undergraduate research is lauded as a high-impact practice owing to the array of benefits that students can reap from participating. One unexplored construct that may affect student intent to persist in research is research anxiety, defined as the sense of worry or apprehension associated with conducting research. In this study, we surveyed 1272 undergraduate researchers across research-intensive, master's-granting, and primarily undergraduate institutions to assess the relationship among student demographics, research anxiety, and intent to pursue a research career. Using structural equation modeling, we identified that women and students with higher grade point averages (GPAs) were more likely to report higher levels of research anxiety compared with men and students with lower GPAs, respectively. Additionally, research anxiety was significantly and negatively related to student intent to pursue a research-related career. We coded students' open-ended responses about what alleviates and exacerbates their anxiety and found that experiencing failure in the context of research and feeling underprepared increased their research anxiety, while a positive lab environment and mentor–mentee relationships decreased their anxiety. This is the first study to examine undergraduate anxiety in the context of research at scale and to establish a relationship between research anxiety and students' intent to persist in scientific research careers.

INTRODUCTION

Undergraduate research experiences (UREs) in the sciences are high-impact practices that can provide students with a suite of benefits (National Research Council, 2003, 2012; American Association for the Advancement of Science, 2011; President's Council of Advisors on Science and Technology, 2012). Specifically, undergraduate research has been shown to enhance student learning and critical thinking (Rauckhorst *et al.*, 2001; Bauer and Bennett, 2003; Ishiyama, 2007; Brownell *et al.*, 2015). In addition, undergraduate researchers report increased understanding and confidence about how to conduct research (Seymour *et al.*, 2004; Russell *et al.*, 2007). Participating in undergraduate research has also been shown to increase a student's chance of graduating with a bachelor's degree in science (Jones and King, 2014; Hernandez *et al.*, 2018) and being accepted into a science graduate program (Hathaway *et al.*, 2002; Carter *et al.*, 2009; Schultz *et al.*, 2011; Eagan *et al.*, 2013). Notably, the more time students spend in their UREs, the more likely they are to gain particular benefits, such as developing problem-solving skills, learning to work independently, and becoming confident in their ability to do research (Thiry *et al.*, 2012; Adedokun *et al.*, 2014; Daniels *et al.*, 2016). Further, students who engage in research longer increase their chances of pursuing a career in science and excelling in graduate school (Russell *et al.*, 2007; Gilmore *et al.*, 2015).

However, not every student who participates in undergraduate scientific research chooses to continue in research. Research conducted across U.S. universities indicates

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*Address correspondence to: Katelyn M. Cooper (Katelyn.cooper@asu.edu).

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that upward of 50% of students who engage in undergraduate research consider leaving their research labs (Cooper *et al.*, 2019; Gin *et al.* 2021). While some of these students consider leaving to pursue opportunities in different labs because of alternative interests, others consider leaving, and may ultimately leave, because of negative experiences in their research labs. Not only are these students often unable to reap the benefits associated with longer research experiences, but negative research experiences in a single lab may discourage them from pursuing careers in scientific research. Specifically, poor research mentoring relationships (Mabrouk and Peters, 2000; Cooper *et al.*, 2019, 2020b; Limeri *et al.*, 2019), student frustration with research (Seymour *et al.*, 2004), and student fear of failure, particularly without constructive feedback (Mabrouk and Peters, 2000; Cooper *et al.*, 2020b), have been shown to cause students to have negative perceptions of research, which may ultimately lead to students choosing to leave their specific research experiences (Cooper *et al.*, 2019; Gin *et al.*, 2021a).

An additional aspect of research that may impact student persistence in both their research experiences and in science generally is research anxiety, which we define as the sense of worry or apprehension associated with conducting research. Anxiety is broadly defined as an unpleasant emotion characterized by subjective feelings of tension, apprehension, and worry (Spielberger, 2013). Researchers distinguish between trait anxiety, defined as a relatively consistent component of an individual, and state anxiety, defined as a response to a specific situation or trigger (Endler and Kocovski, 2001). While trait anxiety is consistent and commonly addressed by counseling and medical treatment, state anxiety can be addressed by altering the trigger causing the temporary state of anxiety (Endler and Kocovski, 2001). We present research anxiety as a specific type of state anxiety that is activated in the context of a student engaging in an authentic research project in a faculty member's lab. Similar to constructs such as math anxiety, statistics anxiety, and library anxiety (Mellon, 2015; Ashcraft, 2002; Onwuegbuzie and Wilson, 2003), research anxiety arises in response to a specific situation: doing research. Other specific examples of state anxiety that have been shown to impact science undergraduates include test anxiety (Ballen *et al.*, 2017; Cotner *et al.*, 2020; Ewell *et al.*, 2022) and anxiety in response to engaging in active learning (England *et al.*, 2017; Cooper *et al.*, 2018; Brigati *et al.*, 2020) and interacting with classmates (Downing *et al.*, 2020; Hood *et al.*, 2021). Each of these types of state anxiety have been shown to negatively impact student performance in the classroom (England *et al.*, 2019; Cotner *et al.*, 2020; Hood *et al.*, 2021). Research anxiety however, has not been explored in the sciences or specifically in the context of undergraduate research. Research anxiety has only been examined in research methods courses (Papanastasiou, 2005, 2014; Papanastasiou and Zembylas, 2008; Papanastasiou and Schumacker, 2014; Eckberg, 2015), conducting library research, writing a research paper (Kracker, 2002; Kracker and Wang, 2002), or in graduate students conducting research (Rezaei and Zamani-Miandashti, 2013; Razavi *et al.*, 2017; Musgrove *et al.*, 2021).

We predict that research anxiety is prevalent among students who have engaged in UREs, disproportionately affects groups that are already underrepresented or underserved in science, and poses a promising target for future interventions aimed to

promote persistence in research. Anxiety is a multifaceted reaction to the threat of failure (Covington, 1992) and therefore is likely disproportionately present in environments where there are ample opportunities to fail, such as in research experiences (Henry *et al.*, 2019; Cooper *et al.*, 2020b; Gin *et al.*, 2021b). While low to moderate levels of anxiety can be beneficial to students, higher levels are thought to be exclusively detrimental (Yerkes and Dodson, 1908; Teigen, 1994). Namely, students who experience high anxiety stand to experience decreased motivation, engagement, and academic performance (McKeachie, 1951; Culler and Holahan, 1980; Seipp, 1991; Fletcher and Carter, 2010; Vitasari *et al.*, 2010), which could in turn negatively impact their UREs and ultimately their career decisions. As we strive to create a more diverse and inclusive scientific community, it is important to note that anxiety and its negative consequences do not affect undergraduates equally. Studies have shown that the following groups are known to report higher anxiety: women compared with men (Misra and McKean, 2000; England *et al.*, 2019; Mohammed *et al.*, 2021), students who are less academically prepared compared with those who are more prepared (England *et al.*, 2019), lower-level students compared with upper-level students (England *et al.*, 2019), and first-generation college students compared with continuing-generation college students (Gaudier-Diaz *et al.*, 2019). Thus, if research anxiety disproportionately impacts students and their subsequent intentions to persist in science, then this may be a factor that contributes to underrepresentation of these groups in science.

In sum, we argue that identifying who is most likely to be affected by research anxiety, how it impacts students' perceptions of science, and what aspects of research alleviate and exacerbate research anxiety can provide foundational information that may be used in future interventions to lessen student research anxiety with the intent to move toward a more diverse and inclusive scientific community. The following research questions guided our exploration of research anxiety among undergraduate researchers:

- To what extent do student demographics predict research anxiety, and is there a relationship between research anxiety and students' intent to persist in science-related research careers?
- What specific aspects of UREs do students perceive alleviate and exacerbate their research anxiety?

METHODS

This study was done with an approved Arizona State University Institutional Review Board protocol (no. 7247).

Survey Development

We developed a survey to answer our research questions and limited our sample to current undergraduates enrolled in U.S. institutions and majoring in the life sciences who had previously conducted or were currently conducting undergraduate research. We chose to include students who had previously conducted undergraduate research to limit sampling bias (Fowler, 2013; Creswell and Creswell, 2017), specifically survivorship bias; we did not want to exclude students who had left research experiences prematurely, as they often report experiencing challenges that students who persist in an experience do not

(Cooper *et al.*, 2019). The survey first asked students: “Are you currently participating or have you previously participated in a scientific undergraduate research experience, such as conducting research with a faculty member or in a faculty member’s lab?” Then, students indicated whether they had only participated in a summer research experience that they did not continue during the academic school year (e.g., a National Science Foundation [NSF] Research Experience for Undergraduates program). Only students who had participated in a URE during the academic year were invited to participate in the survey. Students who had only participated in course-based undergraduate research experiences (CUREs) and not in a research experience in a faculty member’s lab/group were not included in the data set.

To measure students’ research anxiety, we adapted a previously developed scale designed to measure research anxiety in the context of research methods courses (Papanastasiou and Zembylas, 2008). Students responded to statements such as “research makes me anxious” and “research scares me” using a seven-point Likert scale ranging from “strongly agree” to “strongly disagree.” After responding to the statements assessing their research anxiety, students answered two open-ended questions, asking what increases and decreases their anxiety in undergraduate research. We also adapted a question used by Estrada and colleagues (2011) to assess students’ intent to persist in science-related research careers at the beginning and end of their research experiences. Students were asked: “To what extent do you intend to pursue a science-related research career?” and “Prior to your first undergraduate research experience, to what extent did you intend to pursue a science-related research career?” which they answered using a 10-point Likert scale ranging from “definitely will not” to “definitely will” (Corwin *et al.*, 2018). Finally, students answered demographic questions about their gender, race/ethnicity, college generation status, and grade point average (GPA).

To establish cognitive validity of survey questions, seven research assistants conducted a series of think-aloud interviews with a total of 14 undergraduate researchers to ensure that students understood what each question was asking. The survey was iteratively revised after each think-aloud interview until the questions were fully understood by the interviewees (Trenor *et al.*, 2011). A copy of the survey is printed in the Supplemental Material.

Survey Distribution

Our target population was students who had participated in undergraduate research at research-intensive institutions, master’s-granting institutions, and primarily undergraduate institutions. As such, our first step in recruitment was to contact one person at all research-intensive institutions, master’s-granting institutions, and primarily undergraduate institutions in the United States who we thought would have access to a Listserv of life sciences majors at their respective institution and ask if they would be willing to distribute our survey to all life sciences majors. Of the 709 institutions contacted, 87 agreed to send the survey out to their students (a list of each institution represented in the final data set by institution type and geographic region is included in the Supplemental Material). The surveys were distributed in Spring 2019 and Fall 2019, so all of the data were collected before the COVID-19 pandemic. Students were

entered into a drawing to win one of four \$50 gift cards for completing the survey. We are unable to calculate the total number of students who had the opportunity to complete the survey, because we do not know how many students were in each department that sent out the survey. In total, 1272 life sciences majors completed the survey and consented to participate in the study.

Quantitative Analyses

Research Anxiety Measure. In a recent biology education research study, England and colleagues (2019) assessed the validity of the Papanastasiou and Embylas (2008) anxiety toward research scale and found a two-factor solution: an anxiety subscale and a difficulty subscale. We ran a confirmatory factor analysis (CFA) on the instrument to confirm that the two-factor model was recovered in our population. Unfortunately, we did not have good model fit for two of our three model fit indices; comparative fit index (CFI) = 0.85, root-mean-square error of approximation (RMSEA) = 0.13 [90% confidence interval (CI): 0.12–0.14], standardized root-mean-square residual (SRMR) = 0.06. We then split our sample and ran an exploratory factor analysis (EFA) on one half to identify the factor structure that worked in our population and a CFA on the second half of the sample. During our EFA we found that one of the questions, AQ4, showed evidence of cross-loading on both factors and that another question, AQ3, had mediocre factor loading, so both were dropped (factor loadings are included in the Supplemental Material). We ran the CFA on this revised scale and found improved fit, but it still did not meet our threshold (CFI = 0.94, RMSEA = 0.09 [90% CI = 0.07–0.11], SRMR = 0.04). Finally, as we were more interested in students’ research anxiety than their perception of difficulty, we dropped the three-item difficulty scale. With these changes, we were able to create a measure of anxiety with decent model fit (CFI = 0.98, RMSEA = 0.07 [90% CI: 0.05–0.09], SRMR = 0.02). The final items used in the analysis are shown in Figure 1.

Structural Equation Modeling. To test our hypothesis that anxiety during research experiences impacts intent to pursue research careers in the future, we ran a structural equation model. This model had a measurement model component in which the individual items of the research anxiety scale were included to create the research anxiety latent factor. This enabled us to weight the responses on the individual items by their factor loadings as the latent anxiety factor was calculated. The second part of our model involved two regressions with the outcomes of research anxiety and intent to pursue a research career, respectively. To predict anxiety, we included measures of student demographic characteristics (race/ethnicity,¹ first-generation status, and gender²) and learning

¹We collapsed students who identify as Black or African American, Hispanic, Latino/a or of Spanish origin, and American Indian or Alaska Native into one category, which we call Persons Excluded because of their Ethnicity or Race (PEER; Asai, 2020). These students share the experience of being underserved by institutions of higher education; we recognize that the experiences of these students are different, but the small sample sizes necessitated that we pool these identities as a single factor in our analyses.

²We recognize that not all students identify as gender binary (man or woman; Cooper *et al.*, 2020a); however, there were too few students who identified as non-gender binary to include this category in the analysis.

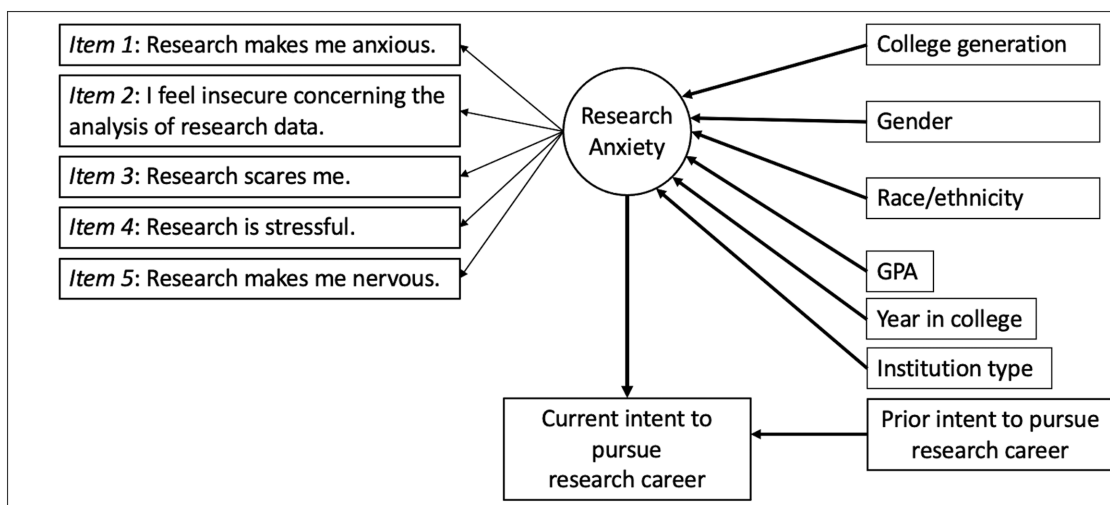


FIGURE 1. Conceptual model illustrating the hypothesized paths exploring the relationships between student characteristics, their anxiety during research, and the impact of that anxiety on intent to pursue a research career after finishing the research experience.

experiences (current GPA and year in college), as these factors have been shown to be related to anxiety in other contexts (gender: Misra and McKean, 2000; Mohammed *et al.*, 2021; race/ethnicity: England *et al.*, 2019; Soria and Horgos, 2021; college generation status: Gaudier-Diaz *et al.*, 2019; GPA: Mohammed *et al.*, 2021; and year in college: Bayram and Bilgel, 2008; England *et al.*, 2019). We included institution type, because the type of institution a student is conducting research at may affect that student's experience (Gin *et al.*, 2021a). In the model, institution type was treated as binary: public research-intensive institutions (RIs) and other institution types (including private RIs, master's-granting institutions, and primarily undergraduate institutions). To predict intent to pursue a research career, we included research anxiety and students' self-reported interest in pursuing a research career at the start of their research experiences. See Figure 1 for the full initial model. The structural equation modeling was carried out in R (R Core Team 2022) using the lavaan package (Rosseel, 2012).

We first tested the fit of the full conceptual model to the data. We used a robust maximum likelihood estimator (MLR) to extract the variance from the data. These robust standard error measurements protect against slightly nonnormal data, which are common for ordinal survey items. Multiple fit indices (chi-square value from robust maximum likelihood estimation, MLR χ^2 ; CFI; RMSEA; and SRMR) were consulted to evaluate model fit. The fit indices were chosen to represent an absolute index, a parsimony-adjusted index, and an incremental fit index (Bandalos and Finney, 2001). Consistent with the recommendations by Hu and Bentler (1999), the following criteria were used to evaluate the adequacy of the models: CFI > 0.95, SRMR < 0.08, and RMSEA < 0.06. Once we identified a model that fit the data, we used model selection based on Akaike information criterion to iteratively prune the model to identify the model that best fit our data. This allowed us to test the hypotheses that student demographics and learning experiences do not directly influence their intent to pursue research careers but may influence this outcome indirectly through differences in research anxiety.

Qualitative Analyses

Two authors (K.M.C. and S.E.B) used open-coding methods to independently review all student responses to the question asking them what increases their anxiety in undergraduate research and the question asking them what decreases their anxiety in undergraduate research. Both reviewers independently reviewed all student responses to both questions to ensure that one individual was not responsible for interpreting the data. Upon the initial review of student responses to each question, the two reviewers took notes and created preliminary categories, which they then compared. The categories created by the coders were similar for each set of responses, and the coders developed a preliminary list of codes from them. For each question, the researchers reviewed half of student responses together and refined their codes. They used constant comparative methods to ensure that codes were not different enough from one another to warrant a separate category (Glesne and Peshkin, 1992). Specifically, to maximize the dependability and confirmability of the qualitative analysis, the researchers compared student quotes to ensure that the description of each category accurately represented all of the quotes within the same group and to ensure that quotes were not different enough from each other to warrant an additional category. The authors created a final codebook for each question (provided in the Supplemental Material). Both authors used the codebook to independently code a randomly selected set of 10% of student responses and compared their codes. Their Cohen's kappa interrater score for the question asking students what increased their anxiety was at an acceptable level ($\kappa = 0.84$), as was their Cohen's kappa interrater score for the question asking students what decreased their anxiety ($\kappa = 0.82$; Landis and Koch, 1977). One author (S.E.B.) coded the remaining data using the codebook. We report out codes that were present in at least 10% of student interviews in the *Results*; codes that were present in fewer than 10% of student interviews are reported in the Supplemental Material. To ensure that our findings would have relevance to contexts beyond the ones specifically studied, we purposefully recruited broadly (from 709 institutions) with the intent to maximize the diversity of participants and of research experiences represented in our data.

TABLE 1. Participant demographics

Student-level demographics	Survey participants <i>n</i> = 1272
Gender	
Woman	74.9%
Man	23.3%
Nonbinary	0.7%
Decline to state	1.0%
Race/ethnicity	
American Indian or Alaska Native	0.5%
Asian	22.6%
Black or African American	4.4%
Latinx	7.0%
Pacific Islander	0.2%
White	59.3%
Other	3.8%
Decline to state	2.2%
College generation status	
First generation	26.5%
Continuing generation	71.9%
Decline to state	1.4%
Year in college	
First year	3.5%
Second year	16.8%
Third year	29.5%
Fourth year or greater	49.6%
Decline to state	0.6%
GPA	
3.1–4.0	86.2%
2.1–3.0	8.6%
1.1–2.0	0.002%
0.0–1.0	0.002%
Decline to state	4.7%
Institution type	
Public R1	60.4%
Private R1	19.7%
Master's granting	11.8%
Primarily undergraduate institution	8.2%

Positionality

At the time this research was conducted, all three authors were serving as research mentors to undergraduate students. Some of us identify as having trait anxiety, and at least one does not. We all conducted undergraduate research in the life sciences and recalled experiencing research anxiety during our research opportunities. We acknowledge that our experiences likely influenced our interpretation of our data, particularly the open-ended coding. However, we purposefully questioned each other's assumptions during the data analysis process to minimize bias.

RESULTS

Participants

A total of 1272 students participated in the study. Students represented institution types that typically engage students in research in a faculty member's lab, including private and public research-intensive institutions, master's-granting institutions, and primarily undergraduate institutions. Participants were

primarily women, white, continuing-generation college students, and in their third or fourth year of college. The average GPA was 3.58 on a 4.0 scale. See Table 1 for a summary of participant demographics. Participants were limited to life sciences majors, defined as those who selected that they were studying biology, biological sciences, or biochemistry.

Finding 1. Research Anxiety Negatively Predicts a Student's Intent to Pursue a Research Career

The initial conceptual model demonstrated good model fit (robust CFI = 0.99; RMSEA = 0.03 [90% CI: 0.019–0.04]; SRMR = 0.02), so we progressed with interpreting the model (see Figure 2).

Testing the Contribution of Student Characteristics on Research Anxiety. The R^2 of research anxiety was 0.02, indicating few of our variables contributed to explaining that latent factor. Of the variables predicting research anxiety, only GPA ($\beta = 0.32 \pm 0.12$, $p = 0.008$) and gender ($\beta = 0.29 \pm 0.12$, $p = 0.015$) were significant and positively related to anxiety. That is, women were more likely to report higher levels of research anxiety than men, and students with higher GPAs were more likely to report higher levels of research anxiety than students with lower GPAs. Although the effects of these variables on research anxiety were small, it is interesting to note that being a man reduced research anxiety by approximately the same magnitude as earning 1 point lower on the GPA scale (e.g., a 3.0 compared with a 4.0; Figure 2).

Testing the Contribution of Research Anxiety on Intent to Pursue a Research Career. The R^2 of intent to pursue a research career was 0.37. Controlling for a student's intent to pursue a research career before the research experience, research anxiety significantly decreased students' intent to pursue a research career after a research experience ($\beta = -0.60 \pm 0.07$, $p < 0.001$). When the standardized coefficients were compared, research anxiety had approximately half the strength of influence as a student's prior intent to pursue a research career and approximately three times the strength of GPA or gender (Figure 2).

Finding 2. Students Reported Fear of Failure and a Perceived Lack of Knowledge Most Commonly Increased Their Research Anxiety

Students most commonly reported that their research anxiety was increased by a fear of failure and making mistakes, a lack of preparation or understanding, the stress of needing to balance their time in research with other personal and/or academic commitments, and insufficient guidance about how to move forward with their research projects. The percentage of students who reported each factor and example quotes are provided in Table 2. Additional themes that were reported by fewer than 10% of students can be found in the Supplemental Material.

Finding 3. Students Reported That Positive Lab Environments and Positive Mentor Relationships Commonly Decrease Their Research Anxiety

Students most commonly highlighted that a positive lab environment, positive relationships with their mentors, feeling as

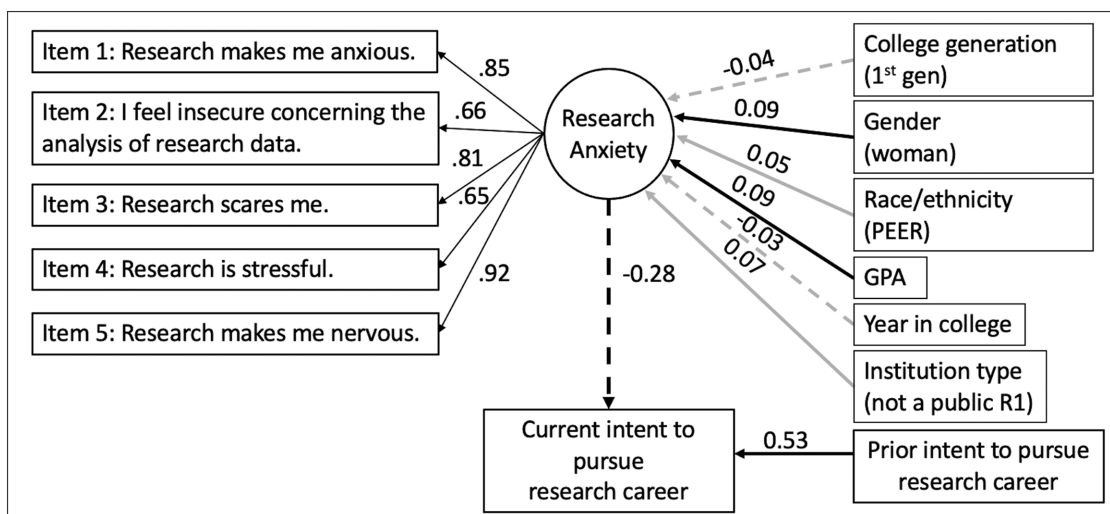


FIGURE 2. The final measurement model showing direct effects of anxiety on intent to pursue a research career and indirect effects of gender and GPA. The model focus groups are indicated in parentheses: first-generation college student (reference group: continuing generation), women (reference group: men), PEER (reference group: white students), not a public R1 (public R1 universities). Regarding the relationship between research anxiety and predictor variables: solid dark lines indicate significant positive relationships; solid gray lines indicate positive relationships that are not statistically significant; dashed dark lines indicate significant negative relationships; dashed gray lines indicate negative relationships that are not statistically significant. The numbers on top of each line are standardized estimates.

though they had sufficient guidance, and receiving praise from a mentor could help decrease their research anxiety. Students also described that increasing their content knowledge and becoming more familiar with lab tasks helped them feel sufficiently prepared for research, which decreased their research anxiety. Additionally, students highlighted that making progress on their research projects could also reduce research anxiety. The percentage of students who reported each factor and example quotes are provided in Table 3. Additional themes that were reported by fewer than 10% of students can be found in the Supplemental Material.

DISCUSSION

This study identified research anxiety as a factor that significantly predicts students' intent to persist in research and found that women and students with higher GPAs were slightly more likely to report higher levels of research anxiety than men and students with lower GPAs, respectively. Women commonly report higher levels of anxiety in college than men (Misra and McKean, 2000; Bayram and Bilgel, 2008), and this has been shown to be true in the context of college science (Bryant *et al.*, 2013; England *et al.*, 2019; Mohammed *et al.*, 2021). Additionally, compared with men, women have been shown to express higher fear of failure, a common factor underlying students' anxiety in this study. Specifically, women enrolled in secondary school tend to report higher levels of fear of failure compared with men (Borgonovi and Han, 2021), which has also been documented among college women in the context of engineering programs (Nelson *et al.*, 2013). Thus, this result of women reporting higher levels of research anxiety is novel, *yet aligns* with prior gendered findings of anxiety.

Perplexingly, high anxiety is typically associated with lower academic performance (McKeachie, 1951; Culler and Holahan, 1980; England *et al.*, 2017; Hood *et al.*, 2021), not higher per-

formance as found in this study. There are a few reasons for why this might be the case. One possibility is that students who are conducting research tend to have higher average GPAs than students not in research (Jones *et al.*, 2010; Hurtado *et al.*, 2014), so the students represented in this study tend to have higher GPAs than a typical undergraduate biology student. Thus, the differences observed in this study are likely a result of differential effects of anxiety for students with high GPAs compared with average GPAs as opposed to low GPAs. Due to the skew in who participates in research, we cannot say whether students with low GPAs have higher anxiety levels. In future studies, it would be important to explore whether students with higher GPAs may be perceived to be capable of more and asked by their mentors to perform more difficult and stressful research-related tasks, consequently increasing their research anxiety. Additionally, if honors programs expect students to complete an independent thesis, then this expectation could contribute to the need to do more difficult and stressful research tasks. However, more research needs to be done to further examine this phenomenon. Based on the data presented in this study, lessening student research anxiety may be a promising way to enhance student persistence in scientific research.

Students' research anxiety may be lessened by helping them to develop adaptive coping skills to handle stressful research-related situations (Musgrove *et al.*, 2021). Musgrove and colleagues (2021) provide descriptions of adaptive coping skills that can be used in undergraduate research, including support seeking and information seeking. By providing explicit instructions for how students can most effectively communicate their needs for emotional and instrumental support in the lab, mentors can aid students in developing these skills. Additionally, mentors can help lessen anxiety by reducing the aspects of UREs that induce stress. This study addresses the second approach by identifying factors associated with undergraduate

TABLE 2. Most common factors that increase student anxiety in the context of undergraduate research

Factors that increase student anxiety in research	Description	Example student quote	Example student quote	Percent of students who reported each factor (n = 1026) ^a
Failure and mistakes	Student's anxiety increases because they feel fear of doing something wrong, messing up, failing, or destroying samples.	Student 51: "Being stressed about why a certain reaction will not work and seeing you did everything textbook right but can't seem to figure out what could have went [sic] wrong."	Student 91: "When I would make a mistake I was worried that it could mess up the entire experiment and my mentor would have to redo everything."	34.7%
Lack of preparation/ understanding	Student's anxiety increases because they feel that they lack the knowledge, understanding, ability, or experience to succeed in research.	Student 27: "Being sent to come up with my own ideas to contribute in subjects I didn't feel secure enough—it increased my anxiety."	Student 25: "Writing papers when my writing skills on the subject are low and working side by side with people who are way more qualified than me. Like PhD, MD and DO next to me who is an undergrad."	29.8%
Time balance	Student's anxiety increases because they perceive that research takes too much time, feel pressure to work a certain amount of time, or struggle to balance research with other commitments.	Student 166: "I often feel like I have a lot on my plate. I want to put a lot of work into research because I care about it, but also not at the expense of my classes. I sometimes feel as if I don't have enough time to do everything."	Student 219: "The pressure to be working as much as I possibly can, although I technically only get academic credit for 12.5 hours of work per week."	15.2%
Insufficient guidance	Student's anxiety increases because they do not have enough guidance or feel uncomfortable seeking help from others about research.	Student 124: "I felt like I did not have enough guidance and was expected to do things alone. [...] I didn't feel ready to do things alone yet and [my mentor] just expected me to do them."	Student 176: "[My faculty advisor] frequently made me feel stupid for asking questions to clarify what I was supposed to do, having no experience in her lab. Additionally, not having any real guidance made the whole situation more anxious."	13.5%

^aOf the 1272 students who completed the survey, 89 student responses could not be coded into one of the reported categories, 52 students did not respond to the question, and 105 students reported that there was nothing that increased their anxiety or that they never experienced any anxiety. Therefore, 1026 students provided a codable response to the question. The percentage of students who reported each category was determined by dividing the number of students who reported the category by the number of students who provided codable responses. Responses mentioned by fewer than 10% of students are provided in the Supplemental Material.

research that students report increase or decrease their anxiety. The most common factor that increased student anxiety was a fear of failure or making mistakes. Learning to cope with failure is perceived to be an integral aspect of UREs (Thiry *et al.*, 2012; Shortlidge and Brownell, 2016; Gin *et al.*, 2018). However, for failure to be productive, students need to feel that they are supported and that they have sufficient guidance to learn from and adequately cope with a failure (Henry *et al.*, 2019). Because it is unrealistic to recommend avoiding failure in research, we instead recommend that mentors provide sufficient guidance as undergraduates encounter and attempt to learn from their mistakes and failures. As the level of guidance that is perceived to be sufficient will differ from trainee to trainee, it is the responsibility of the mentor to be mindful of the needs of their student researchers. Prior studies out of our research group have indicated that student perceptions of insufficient guidance have been reported to cause undergraduates to leave their research experiences prematurely (Cooper

et al., 2019; Gin *et al.*, 2021a). In this current study, we found that students commonly reported that feeling unprepared or having insufficient guidance increased their research anxiety, whereas adequate preparation and sufficient guidance decreased their research anxiety. Undergraduate researchers are typically novice researchers, and many of the tasks and expectations of a research lab are new for them (Thiry and Laursen, 2011). Sometimes UREs are called apprenticeships, which by definition means that they are learning a trade from an expert (Lave and Wenger, 1991). However, these data support the assertion that many students are not receiving the training and guidance that they perceive that they need, which increases their research anxiety.

Additionally, this study adds to an array of literature establishing that lab environments and mentoring have profound impact on undergraduate researchers (Byars-Winston *et al.*, 2015; Aikens *et al.*, 2017; National Academies of Sciences and Medicine, 2017; Cooper *et al.*, 2019; Limeri *et al.*, 2019). In

TABLE 3. Most common factors that decrease student anxiety in the context of undergraduate research

Factors that decrease student anxiety in research	Description	Example student quote	Example student quote	Percent of students who reported each factor (<i>n</i> = 1037) ^a
Positive lab environment	Student's anxiety decreases because of a positive lab environment, which includes feeling as though they belong and/or that they have friends or acquaintances in the lab.	Student 268: "When I work in lab I enjoy the environment and the work. Everyone is so cheerful."	Student 744: "The overall encouragement from everyone in the lab helped. They believe in me when I don't see my worth as a budding scientist."	28.1%
Positive relationship with mentor	Student's anxiety decreases because they have a positive relationship with their mentor or because their mentor is nice, kind, human, relaxed, or approachable.	Student 417: "My postdoc and postgrad lab technician have both been invaluable during my times of stress and we've fostered a good working relationship. I always feel I have a lot to learn from them and am always glad when they trust me with difficult tasks."	Student 271: "My fellow research assistants, postdoc and grad students, and PI are all extremely kind, approachable, and knowledgeable—I never feel as though I am unintelligent or not needed."	26.4%
Sufficient guidance	Student's anxiety decreases because they feel like they have sufficient guidance with their research project, that they can ask questions, or seek help if they are stuck.	Student 28: "My mentors helped me with any questions I had, and the training that I underwent on how to handle different procedures in the lab helped a lot."	Student 182: "The lab manager is very helpful and I was able to ask her and the post doc a lot of my questions and they helped explain things to me and helped guide me though what I needed to do until I got the hang of it."	23.1%
Praise from mentor	Student's anxiety decreases because their mentor provides praise, positive reinforcement, reassurance, validation, or encouragement.	Student 228: "I would always have a lot of nervous anticipation before going into lab but once I was actually there, I had a lot of reassurance from my lab members and mentor. Furthermore, I would recall experiences in the past with my mentor in which I messed up an experiment but she only responded with encouragement and understanding."	Student 129: "Encouragement, support, and validation from my mentors, both graduate-level and the PI, have always helped decrease my feelings of anxiousness."	13.2%
Preparation	Student's anxiety decreases because they have increased their content knowledge or practiced lab tasks or techniques, which often increases their confidence.	Student 2: "After doing different tasks a few times, I would get a lot more confident in my abilities and not feel as anxious."	Student 121: "Practicing the techniques over and over again made me more confident in my skills and abilities which reduced my anxiety when performing the lab work."	11.9%
Progress	Student's anxiety decreases because they feel as though they are making progress on the research project. This includes getting results, doing something independently, or completing tasks.	Student 201: "Completing small tasks in the lab gave me a sense of accomplishment, and it felt good to be able to cross things off my list."	Student 512: "When my experiment progress is good and pleasing for the professor."	11.6%

^aOf the 1272 students who completed the survey, 165 student responses could not be coded into one of the reported categories, 39 students did not respond to the question, and 31 students reported that there was nothing that decreased their anxiety or that they never experienced any anxiety. Therefore, 1037 students provided a codable response to the question. The percent of students who reported each category was determined by dividing the number of students who reported the category by the number of students who provided codable responses. Responses mentioned by fewer than 10% of students are provided in the Supplemental Material.

the current study, undergraduate researchers describe that positive lab environments enhanced their sense of belonging to science, resulting in decreased anxiety. This aligns with prior qualitative work that probed undergraduate researchers' perceptions of positive lab environments, which undergraduates defined as labs where they felt included and socially supported (Cooper *et al.*, 2019). Further, research has demonstrated that students who view their lab environments as positive are significantly less likely to leave their research experiences than students who do not report a positive lab environment (Cooper *et al.*, 2019). Relatedly, undergraduate researchers also highlighted positive mentor–mentee relationships as responsible for decreasing their anxiety. Mentoring in academia has been associated with favorable behavioral, attitudinal, interpersonal, motivational, and career outcomes (Eby *et al.*, 2008), and in the context of undergraduate research is known to promote science identity as well as research self-efficacy (Estrada *et al.*, 2018). Undergraduate research mentors have been shown to provide students with intellectual support, personal/emotional support, and professional socialization (Thiry and Laursen, 2011), all of which would address specific factors that undergraduate researchers identified as underlying their anxiety.

Importantly, research experiences within the life sciences can vary greatly (e.g., fieldwork, benchwork, computational work). Given the design of our study, we were not able to assess whether specific types of life science research resulted in higher or lower levels of research anxiety. However, this is an important question to explore in future studies. Students' anxiety may also vary based on what stage of a project they are engaging in (e.g., research question development, experimental design, data analysis, writing of a manuscript). Studies of students with depression suggest that more guided tasks, such as collecting data or running repeat analyses, may be less stressful than tasks that are unstructured, such as coming up with a research question or having to write a paper based on the results of a study (Cooper *et al.*, 2020b; Gin *et al.*, 2021b). This likely varies based on whether students are receiving intellectual support from their mentors (Thiry and Laursen, 2011). The findings of our study would also suggest that specific aspects of research that are less guided and require in-depth understanding likely evoke more anxiety than those that are more concrete. However, more research needs to be done, considering that the lab environment and role of the research mentor may moderate the relationship between the type of research conducted and students' anxiety.

Limitations

As with any education research study, our findings are limited by who completed the survey. While we intentionally recruited nationally and from departments instead of from selective research programs, it is possible that the students who chose to complete the survey are not completely representative of undergraduate researchers. Notably, we encourage caution in generalizing these results to students engaged in more intensive research experiences such as summer REU programs, as this work was intentionally conducted with students in academic-year research experiences. While the representation of the participants in this study reflect those in other national studies of undergraduate researchers (Lopatto, 2004, 2007;

Russell, 2006), our study is still subject to non-response bias (Sedgwick, 2014); students who self-selected to complete this survey may not be representative of the broader population of undergraduate researchers and may reflect a more motivated group of students. In this study, we asked students about their prior intent to pursue a research career and their current intent to pursue a research career. As such, our study may be impacted by recall bias, defined as the embroidery of personal history by participants (Raphael, 1987). Students not currently conducting research are most likely to inaccurately recall their experiences, but we chose to include these students in the study to limit sampling bias (Fowler, 2013; Creswell and Creswell, 2017), specifically survivorship bias; we did not want to exclude students who had left research experiences prematurely. However, to eliminate potential recall bias, there would be a benefit to conducting longitudinal studies following students with different levels of research anxiety to see whether it leads to differences in persisting in undergraduate and graduate research experiences. Finally, we collected research anxiety at a single time point and it is possible that responses were influenced by recent events in the lab. Future studies should explore the stability of this construct over time to see how it changes and whether these fluctuations have an additive effect on student trajectories in research.

CONCLUSION

In this study we identified that research anxiety significantly and negatively predicts a student's intent to pursue a career in scientific research and that women and students with higher GPAs were slightly more likely to report higher levels of research anxiety compared with men and students with lower GPAs, respectively. Further, we found that students commonly identified experiencing failure in research, a lack of preparation or understanding, and the stress of needing to balance their time in research with other personal and/or academic commitments as factors that can increase their research anxiety. Conversely, students reported a positive lab environment, positive relationships with their mentors, and feeling as though they had sufficient guidance as factors that could decrease their research anxiety. This study identified research anxiety as a novel target for future interventions aimed to increase student persistence in research and ultimately in science.

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