Getting by with a Little Help from Friends: A Qualitative Case Study of Students' Strategies for Coping with Failure in an Undergraduate Biology Laboratory Course

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ABSTRACT

Recent emphasis on research competencies in undergraduate biology education means that more students are doing course-based research. Professional research scientists learn from failed research, but undergraduate students who encounter failure in their biology lab research may not always respond in ways that advance their learning. There is a need to examine individual students' responses to failed research as they conduct investigations in an undergraduate lab course. Here, we report a qualitative research case study based on data from interviews and course work to examine five undergraduate students' emotional responses, coping strategies, and perceptions of learning as they confronted failure in a semester-long intro lab course investigation. All five students displayed negative emotions when they encountered a research obstacle, but their coping strategies varied. However, by the end of their research process, all had responded with competent actions, relationship actions, and autonomous actions as adaptive coping strategies. Support seeking played a critical role to promote autonomy as a foundation for research self-efficacy. After completing their research, the students reported valuable learning from the experience. Implications for instruction are based on examples of coping strategies for managing negative emotions from failed research.

INTRODUCTION

Learning from failure in science is a critical aspect of authentic research experiences, because science is based on uncertainty, iteration, and ambiguity. In fact, professional scientists experience many mistakes before they succeed in discovering new knowledge despite having research plans informed by the literature and designed to succeed. Radoff *et al.* (2019) reported several scientific accounts of uncertainty and confusion from 19th- to 21st-century scientists to illustrate how scientists have experienced and reported coping with negative emotions during research.

Experiencing Failure Is Part of the Process of Learning How to Conduct Authentic Research

Failure for science, technology, engineering, and mathematics (STEM) professionals means not achieving their own expectations of proficiency and, according to a study by Simpson and Maltese (2017), it shapes their professional trajectories while also providing them with valuable skills or qualities. Thus, undergraduate students in science need to experience failure as part of the process of learning how to undertake authentic scientific practices. Simpson and Maltese (2017) suggest that, to help students learn about scientific failure, instructors can avoid scenarios where students expect to get the right answer by engaging students with activities in which they

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should generate different results based on their choices (e.g., in science research labs). In agreement with this suggestion, Gin *et al.* (2018) found that, when the biology students in their study experienced failures that prevented them from achieving predefined research goals, they developed an ability to deal with scientific obstacles.

In the field of physics education, Radoff *et al.* (2019) reported a qualitative research case study based on data from course work and interviews to document the transformation of an engineering student in physics from being worried about correct answers to taking pleasure in working on the challenges and uncertainty of science. This transformation involved managing anxiety when faced with the unknown. They refer to this transformation as meta-affective learning, meaning learning how to feel about feelings (Radoff *et al.*, 2019). But students' coping processes are reported to be context specific, interrelated, and multifaceted (Gin *et al.*, 2018; Hilliard *et al.*, 2020), so to help students manage their feelings, we must understand students' emotional responses as well as how and why a failed research experience might lead to different coping strategies.

Despite Emotional Reactions to Failure Being a Pedagogical Tool, Negative Emotions Have the Potential to Undermine the Learning Process

Undergraduate students taking science courses have varied reactions when they first experience challenges, and their emotional responses are not always productive (Gin *et al.*, 2018; Henry *et al.*, 2019). England *et al.* (2017, 2019) recently explored how students cope with anxiety in undergraduate biology courses. Anxiety arises when students are not sure of their ability to complete a valued task (Pekrun, 2006). England *et al.* (2017) reported that active-learning practices in lecture courses cause anxiety for a variety of reasons, including social anxiety related to fear of answering questions incorrectly in public. Worries about uncertainty of results and pressure for success also include "doing something wrong, looking foolish, or not meeting expectations" according to Peppercorn (2018, p. 2). Altermatt (2007) found that men and women had different postfailure interactions, in that female students' interactions seemed to be more supportive than male students. In fact, they also reported that these interactions can result in negative outcomes for women by leading to worries. Of particular concern, England *et al.* (2017) also found higher anxiety to be negatively correlated with self-reported grade and intention to persist in the biology major.

Negative emotions like anxiety are not always negative for learning, because individuals have the capacity to regulate their emotions through strategies such as coping, and worry and anxiety do not necessarily indicate poor coping strategies. In medicine, Alimoglu *et al.* (2011) studied the characteristics and categorized main coping strategies of medical students as problem focused or emotion focused. They found that most students adopted problem-focused coping, which was positively correlated with satisfaction with practical exam scores. The authors suggested that interventions to address undesired coping strategies might alleviate student dissatisfaction with problem-based learning instructional methods and poor academic achievement.

Students' Reactions to Failure Are Influenced by Personal Characteristics and the Learning Environment

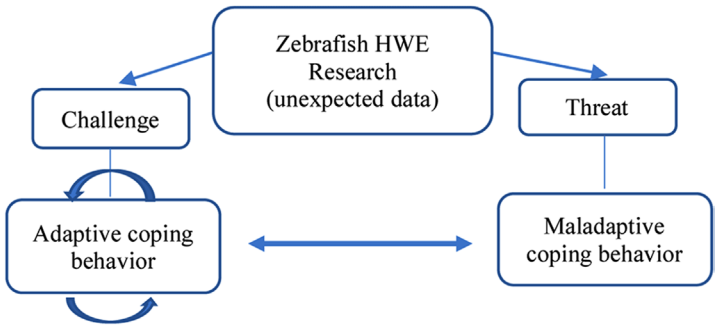
Emotions shape how students interact with their surroundings, and how they cope with emotional responses to academic stress or anxiety can be influenced by their identities, prior experience, and the learning environment (Gross, 2015). Instructors also play a role in this process by helping to guide student emotion regulation. An instructor's engagement or influence on the learning environment provides opportunities for students to learn with and about research. This can be informed by knowledge of factors that influence how students cope with their emotional responses, which is needed for teachers to support student persistence in the face of research failures. Knowledge of coping could help an instructor to re-engage the most challenging or difficult students who experience negative emotions such as anxiety, uncertainty, confusion, feeling daunted, doubtful, frustrated, nervous, overwhelmed, stressed out, or worried (as defined in Supplemental Material 5) when confronting failed research. Students' peer interactions, genders, and perceptions of an achievement-related failure experience are factors that an instructor might consider before attempting to influence their beliefs (Altermatt and Broady, 2009).

Furthermore, student autonomy in the academic setting could be an important factor to monitor based on a theoretical model (Henry *et al.*, 2019). This model proposes that, for STEM undergraduates' coping behaviors in academic contexts, controllable attributions would be associated with adaptive coping strategies, whereas uncontrollable attributions and more negative fear of failure would be associated with challenge avoidance and maladaptive coping. Because little is known about how factors and patterns affecting the importance and impact of failed research experiences on a student's academic trajectory, we examine here individual students' responses and learning outcomes within the framework of their unique characteristics and personal contexts as a way to provide insight into student experiences and potential instructional approaches to guiding student coping with failure.

Self-Determination Theory Is a Useful Theoretical Framework

Here, we report on a case study informed by self-determination theory (SDT; Deci and Ryan, 2008) and the coping system (Skinner *et al.*, 2003, 2014; Henry *et al.*, 2019) as frameworks to analyze five students' failed research experiences. As we were initially attempting to understand student experiences with research failure using grounded theory methodology, the data were kept rooted in each participant's own language (Saldaña, 2013). Later, in reflecting on our coding processes and analyzing coping strategies, we noticed that students' appraisals of stressors determined their ways of coping and emotional responses. The components of SDT were found in our data. Therefore, to frame the rest of this paper, we first summarize how each coping strategy relates to each SDT psychological need portrayed in Figure 1.

In brief, according to the American Psychological Association (APA, 2018), SDT proposes that "behavior varies along a continuum from externally controlled (e.g., to obtain rewards or avoid punishments) to autonomous or intrinsically motivated (e.g., to have fun or explore interests)." Stress is an external event that results in one's negative physiological and



Competence	Problem solving	Helplessness
	Information seeking	Escape
Relatedness	Support seeking	Delegation
	Self-reliance	Isolation
Autonomy	Accommodation	Opposition
	Negotiation	Submission

FIGURE 1. Coping strategies categorized by SDT based on work by Skinner *et al.* (2003).

cognitive distress (Suldo *et al.*, 2008). In Figure 1, unexpected data in the undergraduate lab related to zebrafish research act as the stressor. Coping includes behavioral and cognitive efforts used to manage problems and control emotions caused by stressors (Lazarus and Folkman, 1984). In other words, coping strategies are one's behavioral responses to stressful situations (Skinner *et al.*, 2003). Students' coping strategies aligned with the coping system suggested by Skinner *et al.* (2003), which organizes coping strategies based on one's basic psychological needs according to SDT (Deci and Ryan, 1985; Connell and Wellborn, 1991). These three needs appear at the left in Figure 1: *competence*: "one's developed repertoire of skills, especially as it is applied to a task or set of tasks"; *relatedness*: "a feeling of connection with other people, often accompanied by affection, trust, and a sense of personal security"; and *autonomy*: "the experience of acting from choice, rather than feeling pressured to act" (APA, 2018).

According to Skinner *et al.* (2003), ideas of adaptive coping and maladaptive coping align with a coping system that appraises a stressor as a challenge or a threat. Adaptive coping supports progress toward desired academic outcomes to address problems and promote well-being (Henry *et al.*, 2019). For example, if students perceive a stressor as an interesting challenge to competence, then they are likely to use adaptive coping strategies such as *problem-solving* or *information-seeking* (see Figure 1). In contrast, if students perceive a stressor as a threat to competence, they can adopt maladaptive coping strategies such as *helplessness* or *escape*. Likewise, relatedness includes different coping strategy responses to appraisals of challenge (*support seeking* and *self-reliance*) or threat (*delegation* and *social isolation*), and the SDT need for autonomy includes different coping strategy responses to challenge (*accommodation* and *negotiation*) or threat (*opposition* and *submission*; Skinner *et al.*, 2003). Maladaptive coping strategies can interfere with students' academic success and well-being (Henry *et al.*, 2019). For this study, we simplified the coping system (Skinner *et al.*, 2003, 2014) according to the findings in our data to frame our study, as our primary focus is on explaining and identifying the types of coping strategies and levels of distress during failure in our study. Our data was found to align with components in Figure 1.

METHODS

This study employed an embedded, single-case study design (Yin, 2014) to explore undergraduate students' failed research experiences in a biology lab research course in depth. A case study is defined as "an empirical inquiry that investigates a contemporary phenomenon (the 'case') within its real-life context, especially when the boundaries between phenomenon and context may not be clearly evident" (Yin, 2014, p. 16). With a case study approach, we wanted to examine how and why individual biology students applied coping strategies when encountering a research challenge; how and why their coping behaviors changed; and what students learned, using data from a qualitative study of individual students' experiences when they confronted a failed research experience. To understand undergraduate students' responses to their lab experiences as they faced challenges or failures in a biology laboratory course, four research questions guided our study.

Research Questions

1. How did failed research experiences impact students' feelings as investigators?
2. How did students approach their research challenges?
3. What are the common patterns of relationships in their coping behaviors, and where did five students' responses to research challenges diverge and why?
4. What learning or knowledge did students perceive gaining from their failed research experiences?

A case study is preferred when the study intends to explore "how" and "why" questions, when investigating contemporary events, and when the related behaviors cannot be controlled (Yin, 2014). This study intended to explore "how" and "why" questions regarding students' responses to research challenges that they interpreted as failed research. The phenomenon being explored was an atypical event, which was encountering unexpected challenges when their research subjects failed to thrive as expected, thus the students' behaviors were not manipulated.

Researcher Positionality and Context

The authors are a Caucasian woman course director who developed the lab activity and taught the lecture for the intro biology course (N.P.) and an Asian woman graduate student who also participated in one lab section as a volunteer instructor (S.W.S.). Both researchers wanted to deeply understand perspectives about and responses to an experience in lab that students who volunteered for this study perceived as a failure. The Asian woman, based on her previous academic training in positive psychology, was interested in exploring factors that contribute

to student well-being as background for her doctorate in science education. To understand the student experience, she participated in one lab section of the course as a student. The next day, she then assisted with another biology laboratory section as a volunteer instructor who guided students, but she was not involved with any grading of student work. As a student, she learned and observed students' activities, interactions, and research processes, and as a volunteer instructor, she focused on the learning activities and expected outcomes to understand the context of the course. As course director, the Caucasian woman (N.P.) trained graduate students (GTAs) and peer leaders as lab instructors to mentor the student research teams. The peer leaders were undergraduate teaching interns (UTIs) who had previously completed the lab and then came back to mentor two teams of undergraduate student investigators. Both authors wanted to learn something that could lead to course improvements based on an in-depth examination of lived experiences from students' thoughts about their team investigations and perspectives on research that did not work out. We understand and are aware that our positionalities make us experience the lab differently than our participants who took the lab as a required course for a grade. The first author adopted the role as a curious researcher when conducting the interviews, and not as an instructor who would teach or evaluate the research teams. The Semi-structured Interview Protocol, approved by Purdue Institutional Review Board (IRB no. 811021367), is provided as Supplemental Material 1. As teaching staff or from a student role, we have insider perspectives into the research (Merriam, 2009). Therefore, we tried to be cautious and kept our data in the students' own words to avoid infusing our own perspectives and biases as insiders into this study.

While working with the teams and reading assignments submitted by students, the authors, GTAs, and UTIs found several students to be struggling with research challenges, such as finding unexpected data or lack of data, which is not unusual in a course-based investigation. These students showed various behavioral and emotional responses to shared challenges. Through observation and interviews, this case study was designed to understand students' experiences and to suggest ways to appropriately help students in the future when they confront research failures.

Students Experienced Failure when They Conducted a Zebrafish Population Study in an Introductory Biology Laboratory Course

In the case study course, students had a laboratory preparation lecture (45 minutes) and a laboratory session (180 minutes) each week of the semester. There were three research modules with weekly structured introductions. Examples from the lab manual are provided as Supplemental Material 2. For one of the modules, students worked throughout the semester with a population of zebrafish (*Danio rerio*) in isolated tanks. In brief, by analyzing the changing proportions of zebrafish phenotypes, the students could conclude whether evolution had occurred in the populations in their tanks. In lecture, students from different sections who were working on the same fish tank were sometimes given 15 minutes to share and refine their research questions, to compare data-collection plans, and to propose alternative ideas for addressing research challenges. Most teams started by examining the proportions of different zebrafish phenotypes to make predictions about allelic frequencies of observable traits and detect evolution in their populations according to the Hardy-Weinberg equilibrium. They expected their populations to grow; however, there were occasions when the zebrafish did not breed or the offspring did not survive, which were examples of some of the perceived research failures that students experienced.

Teams of three students designed their own research methods to collect, organize, and analyze data over the course of the semester. They decided who would serve as principal investigator (PI) for this research module in the lab course. Volunteer students who were selected to participate in this study all took charge of the zebrafish research module as PI, meaning that they assigned roles for their team members, checked that everyone understood what was done or studied, planned the research, coordinated an oral presentation to share results with the class, and wrote a manuscript in the classic scientific style that was peer reviewed by other members of their team who suggested revisions. The PIs then submitted final written reports about the zebrafish population research at the end of the semester.

Five Student Participants Were Selected for This Study

A failed research experience in a research-based biology laboratory program in the 2018–2019 academic year is a case, because it is considered a bounded system restricted by time and location (Merriam, 2009). Because each student was selected from the same program and experienced the targeted phenomenon, an individual student is an embedded unit of analysis in the context of this single-case study (Yin, 2014). An embedded single-case study with multiple units of analysis using techniques that promote the trustworthiness of the data—such as member checking—is most appropriate to provide readers with a vicarious experience by illustrating a detailed description of each student's experience with failed research (Yin, 2014).

This case study used purposeful recruitment of student volunteers, meaning the researchers selected five student participants intentionally from numerous volunteers. This gave multiple forms of data to generate rich description and gain insight about consensus experiences as well as patterns of variability (Merriam, 2009; Creswell and Poth, 2018). Because five students were recruited, the study had five embedded units of analysis. The first recruitment criterion included only undergraduate biology students in a midwestern university who completed the laboratory course described earlier and who were invited and volunteered to participate in this study. Supplemental Material 3 provides the recruitment email (approved by Purdue IRB no. 1811021367). The second criterion included only students who self-identified as having experienced challenges due to unexpected data or perceived failure with a zebrafish investigation conducted in the laboratory course. With these criteria, participants were selected to represent a diversity of undergraduate biology students.

Information about the five students who met the criteria, such as their background, motivations, expectations, and career goals, was self-reported during interviews, as detailed under *Data Collection*. The participants' different backgrounds included different academic levels, career goals, prior knowledge, and personal characteristics. The five students were deidentified with pseudonyms: Lilly, George, Jack, Emily, and

TABLE 1. Self-reported information about the participants from their interviews

Student pseudonym	Level	Gender	Major	Underrepresented minority (URM)	Career goal
Lilly	First-year	Female	Biology	Not URM	Naturalist
Emily	Second-year	Female	Exploratory studies	URM	Anesthesiologist (later, psychologist)
George	First-year	Male	Biology	Not URM	Medical school
Jack	First-year	Male	Biology	Not URM	Biology research
James	Fourth-year	Male	Biology	Not URM	Biology research

James (see Table 1). With this small group of participants, in the context of the biology lab course, it was possible to intensely examine each individual's complex real-life experience (Merriam, 2009). All five participants were faced with the challenge that the zebrafish in their tank did not breed or the offspring did not survive. A brief description of the zebrafish lab protocols with mention of the scientific challenges and associated references to the research literature are detailed in Supplemental Material 4.

As PIs of their teams' zebrafish research, all five participants encountered similar research challenges according to their submitted course work. Lilly, George, and Jack were in three different lab sections and all three studied the same 10-gallon tank that started with 15 adult zebrafish. Of these, 12 were wild type and three had a recessive phenotype. Their tank also started with 36 fry of the recessive phenotype, but only one survived. James was in the same lab section as George but was studying a different tank that started with nine wild type and three recessive phenotype adult fish plus 23 fry. Only one of these 23 fry was still alive and grew to the adult stage by the end of the semester. Emily was in a different lab section, and she studied a tank that started with 12 zebrafish that all had the wild-type phenotype. Even though all of these parent fish had zebra stripes, an unknown number were heterozygous for the recessive trait, because when 40 eggs were collected from Emily's tank and 23 hatched, one fry had the recessive phenotype. However, none were raised to the adult stage. The participants who addressed this research problem are briefly described in Table 1, and more detail is provided below with the relevant results.

Data Collection

Multiple sources of information were collected for this case study. Two semistructured interviews, including a one-on-one interview and a follow-up phone interview, were conducted. In addition, students' initial plans for their research, final papers, the course syllabus, lesson plans of the zebrafish module, a lab manual, and materials related to the zebrafish module, including articles, Web pages, and quizzes provided to the students were collected throughout the 2018 Fall semester (Table 2). During the follow-up interview, member checks were conducted to promote the trustworthiness of findings by verifying the analysis of the data with the participants.

To examine the students' experiences of failure at the different stages, semistructured interview questions were arranged chronologically: before, during, and after failure. The interview aimed to explore each student's expectations, motivation, and emotions about open-ended research before failure, and it also aimed to probe the participants' emotions and behavioral reactions as they dealt with research challenges. The questions sought to comprehend participants' understanding or perceptions about their failed research experiences. The final questions were about their background and demographic questions to understand each participant's situation, including prior research experiences and identity.

Data Analysis

This study used thematic analysis (Braun and Clarke, 2006) and followed five phases of data analysis (Table 3) to identify patterns and relationships within the data (Braun and Clarke, 2006; Merriam, 2009; Saldaña, 2013). For the first cycle of coding, the primary and secondary data were reviewed. In particular, interview transcripts, students' initial plans for their zebrafish research, and final papers were used as primary sources to examine students' coping strategies and understanding of the zebrafish module. Other documents, such as lesson plans for the zebrafish module, the lab manual, and other materials that had been provided to students, were used as secondary sources to understand the general context of the course and the students' use of these materials. The secondary documents also were used as part of the process of developing coding themes and categories for this study. Analytical memos were generated from the students' interview transcripts, initial plans, final papers, and course documents. Codes were developed by using descriptive coding and emotion coding by representing participants' actions and emotions with their own words and phrases (Saldaña, 2013). Codebook examples and a glossary with definitions of emotion terms and example quotes are in Supplemental Material 5, which also shows how the codebook changed according to the steps in Table 3. Through these steps of coding stages, each participant's emotional and behavioral responses to research challenges were identified.

TABLE 2. Data collection

	Semester start	Course work	Semester end		
Data collection	Initial research plans	Syllabus, lesson plans of the zebrafish module, a lab manual, student assignment artifacts, and other educational materials	Final research reports	One-on-one interviews	Follow-up interviews

TABLE 3. Phases of data analysis

Phase	Analysis strategies	Descriptions
1. Understanding the data and generating initial codes	Analytical memos Descriptive coding Emotion coding	Identified the students' behavioral and emotional responses to research challenge
2. Developing categories	Axial coding Focus coding	Organized and agreed on how to code data into categories and subcategories
3. Identifying themes	Cross-analysis Process coding	Understood overall patterns and sequence of coping strategies for each unit of analysis (individual participants) as well as SDT patterns and interactions across cases
4. Analyzing the data based on the theories	Analytical memos (NVivo 12)	Explored patterns, relationships, and counted instances for each code
5. Validating the dependability and confirmability of the data codes by consensus	Compare counts for transcript instances independently coded by two authors.	Refined glossary in an iterative process until consensus could be reached on counts of coding instances in transcripts from a subset (two) of the participants.

In the second cycle of coding, categories and major themes from the words of individual participants were developed by using axial and focus coding to categorize coded data according to thematic commonality and to understand the relationships between the categories and subcategories (Saldaña, 2013).

In a third cycle of coding, the data across the embedded units of analysis were analyzed to come up with consensus themes (i.e., cross-analysis triangulation from comparing individual processes for five participants). Because this study focused on the sequence of how students confronted failure, we used process coding (Saldaña, 2013) to particularly describe the sequence of actions or interactions that students had during failure. Cross-analysis—comparing and sorting the coded data—made it possible to understand the overall patterns and interactions of all students' behavioral and emotional responses. The coding enabled one author (S.W.S.) to explore coping strategies associated with specific events that were reported in the interviews, which revealed patterns consistent with the idea to map the coded data according to the SDT framework and our research questions. With another coder, the subcategories and major themes were then defined to categorize students' emotions and responses. The data were iteratively recoded and recategorized when codes were compared between coders. Through this process, two coders agreed upon themes from the outcome of coding, and categories were defined.

Finally, codes and themes were analyzed using NVivo 12 to explore patterns, relationships, and counts of codes and themes. To maintain dependability and to check for confirmability, we chose to use collaborative qualitative analysis throughout our coding processes (Richards and Hemphill, 2018). Compared with just interrater reliability, consensus coding allowed us to discover credible complexities in the data (Denzin and Lincoln, 2005; Stanton *et al.*, 2015, 2019). The codes for each conversational segment in the interviews were compared, and in cases of disagreement, we discussed them until we were able to come to consensus. To clarify our consensus, we modified the glossaries. The coping strategies glossary is in Table 4, whereas the codebook and a glossary of emotion codes are in Supplemental Material 5 with data examples.

To check validity, the various sources of data were triangulated, including interview transcripts, students' initial plans and final research papers, and follow-up interviews to check and compare data from the participants (Merriam, 2009). Triangulation also refers to the use of at least three data sources for a claim, with all sources being equal. For example, three different participants all independently stated in interviews that they sought help from a peer or instructor to help them sift through the published literature to understand how to address the problem of water quality for breeding fish. Their initial research plans and data tables show a plan to measure pH and temperature of the aquarium water. Their final research papers show references regarding water-quality parameters that are optimum for breeding fish. Thus, multiple sources of data confirmed the strategies for solving an aquarium water-quality problem. Their course work artifact examples are not provided to protect the identity of individual participants in this study. Instead, preliminary analysis was presented to the participants, and feedback was received in a second interview about the interpretation to understand the participants' perspectives (Merriam, 2009).

Analysis of Coping Strategies

Based on the SDT coping system (Skinner *et al.*, 2003; Henry *et al.*, 2019), each term was defined and illustrated using a quote from our findings, as detailed in Table 4. Student quotes in the *Results* were edited slightly for grammar, punctuation, and removing filler words that do not change the meaning of the quote ("like," "kinda") so that the quotes are easier to read. Helplessness, isolation, and opposition are not listed in Table 4, because they were not found among the themes or subcategories in our data.

RESULTS

Students Brought Different Characteristics to a Biology Laboratory Course

George, Jack, and Lilly were first-year students who majored in biology. James was a fourth-year student who changed his major from liberal arts to biology. Emily was a sophomore who was a part of the exploratory studies program, which allowed her to take several courses in different disciplines. All five participants were initially interested in pursuing careers in biology fields, yet Emily later decided to major in psychology (Table 1). The students came into the biology lab course with different dispositions and characteristics, such as previous lab experiences, prior knowledge, motivations, and career goals (Table 5). According to their interview responses, students' initial

TABLE 4. Glossary of code definitions and examples of coded coping strategies

Self-determination theory (SDT) Code terms	Coping strategy subcodes	Definition	Example*
Competence One's developed repertoire of skills, especially as it is applied to a task or set of tasks (APA, 2020). In SDT, feeling competent is necessary to perform intrinsically motivated behavior (Deci and Ryan, 2000).	Escape	Students' actions of disengaging or avoiding the stressor by isolating themselves (modified from Henry *et al.*, 2019).	"I know when it eventually became obvious, like the fish weren't going to reproduce. I know for a week I just sort of just shut down completely. I was in the midst of a depressive episode. Didn't really do anything. I didn't have the motivation to."
	Information seeking	Students' attempts to gain more information about a challenging condition, such as causes, results, and the meaning of the stressor by observing and researching the problem (modified from Henry *et al.*, 2019).	"I did online searches... like on [water] testing by looking at research articles. But there is this report [the assignment], so for data you keep tracking the numbers and how they were fed and the temperatures of the tank. So, a lot was looking at that [the records] but also looking at other factors... at how clean the tank was, especially looking at the flow-through nursery."
	Problem solving	Students' efforts and attempts to address the stressor by coming up with ideas, making a plan, strategizing, and implementing a plan (modified from Henry *et al.*, 2019).	"I targeted the question towards why the zebrafish didn't reproduce. And the data I got, which was the only data that I could collect, were the conditions in both my tank and another tank which had fish that did reproduce."
Relatedness A feeling of connection with other people, often accompanied by affection, trust, and a sense of personal security (APA, 2020). In SDT, building a relationship with others can play a role in one's intrinsic motivation and behavior (Deci and Ryan, 2000). Students sought social and/or emotional support to resolve the problem or to relieve their emotions to the stressor (modified from Henry *et al.*, 2019).	Problem-focused support seeking	Students' efforts to seek help to manage the stressor by getting ideas/support to resolve a problem (modified from Lazarus and Folkman, 1984, p. 150).	"I guess my group communicated really well. We talked a lot even outside of class about things. So even about their experiments as well. We came up with a lot of different ideas for things... We liked talking about the things that were going on and things maybe like that the other people maybe weren't thinking of so we came up with ideas for each others' experiments."
	Emotion-focused support seeking	Students' attempts to share their emotions or receive support to regulate their emotions to the stressor.	"Definitely [I] felt like better about my situation because originally it had been like, it feels kind of alone whenever especially within my lab section, both my partners, lab partners had data to work with. And I didn't. And that was worrisome for me. But knowing that other people have the same problem. And they were working through it too."
Autonomy The experience of acting from choice, rather than feeling pressured to act (APA, 2020). In SDT, feeling autonomous (not controlled) is a human essential need for one's motivated behavior, psychological growth, and well-being (Deci and Ryan, 2000).	Accommodation	Students' actions of accepting the stressor and constraints. Students understand the nature of science and accept the constraints related to completing the research project (modified from Henry *et al.*, 2019).	"I wasn't really sure if I was doing it the right way. But … It's just the fact that it was so open ended meant that there are a lot of ways you could do it."
	Cognitive restructuring	Students attempt to adopt a positive or negative perspective of a stressful situation. Students' perceptions or definitions of the stressor after completing the project (modified from Henry *et al.*, 2019).	"I'd say failure is whenever you don't get what you're looking for but then also on top of that you don't get any kind of new knowledge from the experiment you conducted because I feel like if you come out from an experiment, even if it's not what you thought it was going to be, and you still learned something then it's still beneficial, not necessarily a failure."

*Example quotes are in the students' own words with very minor edits only when needed for clarity.

TABLE 5. Students' reported characteristics and coping process

Students (pseudonyms)	Before				During		After		
	Prior knowledge	Previous lab experience	Initial expectation	Motivation	Emotional reaction	Coping strategies	Perception of failure	Perception of learning	Research self-efficacy
Lilly	Some wrong knowledge about Hardy-Weinberg, but applied it	A structured lab experience	Would have no trouble	Grade, desire to learn	Worried, anxious	Information seeking Problem solving Support seeking	It was not a failure	Valuable	Felt more confident
Emily	Did not elaborate on Hardy-Weinberg but applied it	No college lab experience, no chemistry course or lab	No stated expectation	Grade, responsibility, curiosity	Overwhelmed, stressed out	Information seeking Emotion-focused support seeking Problem solving Accommodation	It was a total failure	Valuable	Felt a sense of accomplishment but lacks the ambition to do research
George	Elaborated upon the Hardy-Weinberg model and applied it	A structured lab experience	Would be difficult and would need a lot of work	Desire to learn	Frustrated, doubtful	Information seeking Support seeking Accommodation Problem solving	It was not a failure	Valuable	Felt more confident
Jack	Did not elaborate on Hardy-Weinberg but applied it	A structured lab experience	Would complete it even if it would be complicated	Grade	Daunted, stressed out	Escape (maladaptive) Support seeking Problem solving Information seeking Accommodation	It was not a failure	Valuable	Felt more confident but insignificant
James	No answer (was confused)	A structured lab experience	Unsure of his ability and the research process	Desire to learn	Nervous, frustrated	Information seeking Support seeking Accommodation Problem solving	Failure is okay	Valuable	Felt more confident

expectations about their abilities to conduct open-ended research were varied. Lilly thought that her research would go smoothly based on her previous laboratory experience in high school, which was very structured and designed to follow a certain protocol. All but Emily were taking an undergraduate chemistry lab course in which the research was structured, so they had no previous or concurrent experience with authentic research for which the answer is unknown. Jack, George, and James expressed low expectations or worries about their abilities to conduct open-ended research. These initial expectations were related to their characteristics and other lab experiences. James stated,

> I am very self-critical in general. So, initially, I was very nervous about myself. I wasn't really sure if I'd be able to do it.

Emily said that she did not have an expectation about her ability to conduct open-ended research, because she had not had any experience conducting research as a PI. In terms of motivation, Emily, Lilly, and Jack mentioned that they were motivated to get a good grade. George, James, Lilly, and Emily also stated their desire to finish the course and to keep pursuing their academic goals, which required this lab class.

Students Expressed Similar Emotional Reactions to the Challenge Regardless of Their Backgrounds

All five students initially expressed negative emotions when they described their responses to failed research with feelings of stress. Negative emotions were expressed regardless of their prior knowledge, previous lab experiences, and initial expectations. Table 5 shows the reduced data to summarize the variation in five replicates in terms of each student's reported characteristics and emotions. Students used various expressions to report their feelings. For example, they felt frustrated, worried, overwhelmed, anxious, daunted, doubtful, and stressed out.

Students gave several reasons for why they felt so bad. The major reasons for negative emotions were uncertainty and worries about grades. Lilly stated,

> Having this trouble definitely brought some uncertainty into what exactly I was going to do.

Uncertainty includes two meanings: they were not sure of practical ways to solve the problem and they doubted their ability to come up with the correct idea, both of which are related to students' competence. All of the students expressed their struggles with finding practical solutions to resolve the challenge. While some students expressed doubt about their capacity to solve the problem (e.g., Jack, George, James), others worried about getting a good grade, because the project paper was a major part of the grade (e.g., Jack, Emily, Lilly). Emily said,

> I was a little overwhelmed because I had no idea what I'm going to do. I had to write a paper on this and [this paper was] a major part of my grade.

Even though grades led to negative emotions, students also mentioned grades as motivation to get through this challenge (e.g., James). Additionally, because the open-ended research project was new to them, and the students had only experienced structured labs in which the outcomes were already known for each protocol, several expressed concerns about knowing what to do when faced with the unexpected. Jack stated:

> Before actually doing the work on it that sort of stressed me out … because I had no idea whether I was right or wrong really.

The students were apparently depending on grades to indicate whether their answers were right or wrong.

Negative emotions were also caused when a student thought about the research challenge in comparison to the lesser burden other teams perceived when the adult fish in other tanks with different phenotypes had laid more eggs. Emily stated:

> I heard so many times people talking about how the PIs for this tank had the worst [research project] because we didn't have anything to go off of.

Also, some students indicated that the semester-long process of data collection in the zebrafish project, which was different from the other lab research modules, was a component that would prolong their stress (e.g., Jack, James). Even though these negative emotions revealed stress, students' emotions led to responses. For example, the anxiety James felt influenced his learning positively, because the research challenge encouraged him to communicate with his group members more actively. In this sense, they acted on negative emotions reflecting their uncertainty and anxiety about having the ability to do the research or solve a problem.

Another reason for negative emotions reported by some students was a concern of judgment from peers. James stated:

> I wasn't really sure if I'd be able to do it. And I thought I'd be letting my group down by not being able to research and analyze well… I never feel like I'm as quite on the same level as everyone else.

The perception of his low competence compared with peers was expressed as nervousness. Also, Emily described the burden of becoming a PI. Emily said:

> I wanted to be able to answer questions from my team members if they had questions, so I wanted to know enough about this topic, zebrafish. To be able to make sure that my investigation was going well, running smoothly… I guess that's what I expect of myself as a PI.

She perceived that taking responsibility as a PI was a source of stress.

Adaptive and Maladaptive Coping Strategies Were Related to Competence, Relatedness, and Autonomy

Students demonstrated adaptive coping strategies related to competence, relatedness, and autonomy, which are the three basic psychological needs of SDT (see Figure 1). Each student demonstrated a unique process of dealing with the research challenge (Figure 2), although the coping behaviors were interrelated and context dependent. A previous coping strategy led

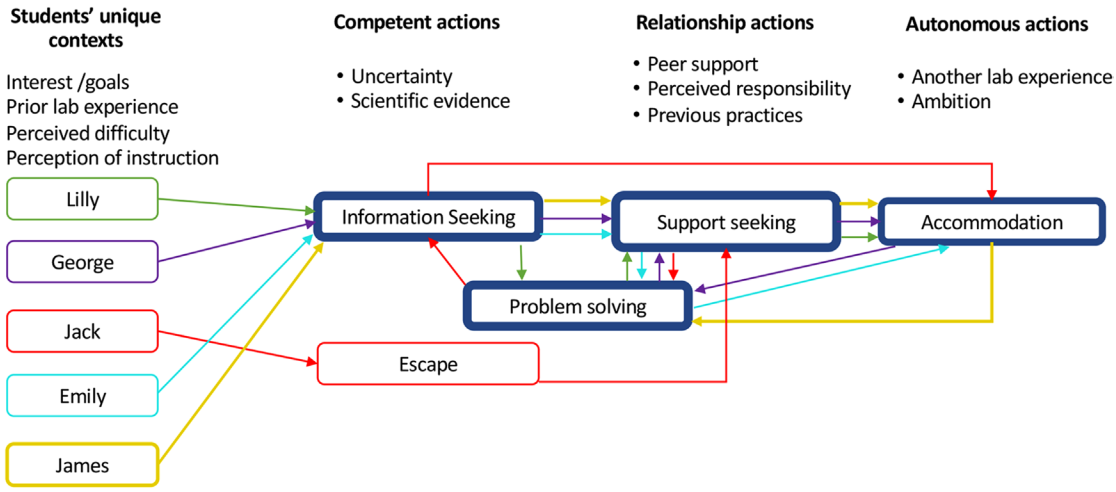


FIGURE 2. Individual sequences of coping strategies throughout the research process.

to the following strategy, and several coping strategies often occurred simultaneously. For example, in the case of James, when he tried to solve the problem, he explored the information and then reached out to group members first before he predicted the fish were experiencing feeding problems: perhaps they were not getting enough food. Then he reached out to teaching staff to solve the feeding problems as a possible cause of fry deaths. In other words, in addition to information seeking, James sought help, which is support seeking, to resolve the problem, which is problem solving. In contrast to James, Jack explained that he experienced a depressive episode. His initial response was to escape (a maladaptive strategy), but then he sought help and came up with ideas to solve the problem, which was an adaptive problem-solving coping behavior. Also, while Jack tested and compared the tanks, he acquired data from another team, which means that he established relationships for problem-focused support seeking, and he did online searches to find possible reasons for the fry deaths, which is information seeking. Thus, James and Jack described that they practiced different types of adaptive coping behaviors in a sequential and concerted manner autonomously and independently to address their negative emotions.

Additionally, the degree and extent of coping strategy use was different according to each student's context (summarized in Table 6). For instance, when Jack and Emily sought help from their peers, they described that they did not get helpful support. In contrast, George, Lilly, and James explained relatively successful support from their peers. In this sense, the reasons for their unique processes and different degrees of using coping behaviors were related to their different contexts, including their perceived competence, relational support, perception of failure, and unique individual characteristics.

Competent Actions

In terms of competence in SDT, all five students demonstrated information-seeking and problem-solving strategies, both of which are adaptive coping behaviors. These competent actions were closely related to students' perceived abilities to solve a problem, which were also influenced by relationship and autonomous actions. As mentioned earlier, when one student did not feel competent to perform a task, the student initially exhibited escape as a maladaptive coping strategy to deal with his high level of anxiety. However, anxiety does not mean the student did not have coping strategies. Over time and in spite of some delays, all students demonstrated adaptive coping strategies related to competence. When all five students first showed self-doubt and nervousness to resolve a problem, they attempted to search for more information, which is information seeking, an adaptive action of competence (e.g., Lilly, George, Emily, James). Jack was the one student who initially did not adopt an adaptive coping strategy until he received social persuasion or feedback validating his ideas and capabilities. In the case of

TABLE 6. Each participant reported coping strategies used to address emotional stress from failed research[a]

		Competence actions		Relationship actions		Autonomy actions	
Students	Gender	Information seeking	Problem solving	Emotion-focused support seeking	Problem-focused support seeking	Accommodation	Cognitive restructuring
Lilly	Female	1	3	5	2	0	6
Emily	Female	10	5	1	3	2	7
George	Male	14	14	3	15	6	6
Jack	Male	6	7	6	7	4	9
James	Male	8	9	2	5	6	4

[a]Numbers indicate how many conversational segments in their initial and follow-up interviews included mention of doing that type of action. Two authors reached consensus on coping strategy definitions (Table 3). To maintain dependability and to check for confirmability of counts, we used collaborative qualitative analysis for the coding process, as consensus coding allowed us to discover credible complexities that are reported for each participant in the narrative.

Jack, his maladaptive behavior, escape, was in response to feeling uncertain about his ability to solve the problem and his desire to complete the course with a good grade. Jack said:

> I know when it eventually became obvious. The fish weren't going to reproduce. I knew for a week [and] I just shut down completely. I was in the midst of a depressive episode. Didn't really do anything. I didn't have the motivation to.

Jack isolated himself in his room most of that time, but he came up with several ideas to solve the problem. However, he felt confused and uncomfortable, primarily because he doubted his ideas. Jack stated:

> I was able to come up with an idea … It's just I wasn't really sure if that idea would be right.

Meanwhile, Jack was very surprised by some positive feedback from his teaching staff on his written test. He felt the test question was very open-ended and vague, so he did not expect his answer to be right. Jack said:

> It was especially surprising with the written test because apparently, I was told by one of my TAs that I got one the best scores in the class, which I thought was really surprising, to be honest… I didn't really expect it to be right…and that was apparently one of the most interesting answers that the TAs got for that answer. I pretty much got it perfect I believe. At the beginning I'd feel incredibly uncomfortable … But then afterward it turns out I was doing fine.

This positive feedback enabled Jack to perceive his ability and ideas were competent. Jack stated:

> Afterward, I still felt uncertain, just not as much as I was originally … They [the teaching staff] did give me some good feedback on my tests and that's what motivated me more. They gave me positive feedback on the test but not the zebrafish research itself, but like them telling me that I did well on it made me feel better about what I was currently doing.

Even though the feedback was not directly related to the research challenge, the positive feedback allowed him to see his competence and ability to complete a difficult task. The teaching staff member's persuasion was not an unrealistic boost, because Jack's good test performance supported the persuasion. Both social persuasion (a relationship action) and the evidence of his competence increased Jack's motivation and engagement in solving research obstacles.

After his competence was validated, Jack explained that support seeking was closely related to his competent actions. Figure 2 shows that, unlike Jack, the other four students showed competent actions to initially address their negative emotions, whereas Jack's maladaptive behavior was modified by following relationship actions that helped him feel confident about his ability to solve a problem. After Jack's competence was validated, he continued to demonstrate support seeking by reaching out to the professor and by sharing his ideas to solve the research problems and describing his emotional difficulties. His ideas were validated again by the professor, and he also received appropriate support for his emotional challenges. Based on these conversations, Jack demonstrated competent and autonomous action, because he revised his research question (accommodation) to instead target why the zebrafish did not reproduce, and he investigated possible causes of infertility. In a similar sense, competent coping strategies were closely related to support seeking by Jack, James, and George.

Additionally, when students adopted coping mechanisms related to competence, four of the five students started by adopting information seeking. Students did not use problem solving at the beginning of their coping processes. They first wanted to gain more information about the problem. Students reported needing some time to feel confident in their knowledge and abilities before they could strategize a solution. They required more information about the situation before they could start to solve a problem.

Relationship Actions

All five students used support seeking, such as problem-focused or emotion-focused support seeking, to receive help with both their research problems and their emotional distress. Support seeking was closely related to students' competence. It helped students decrease their self-doubt about their own ideas, because they were able to build a collective idea or confirm their ideas with others. Support seeking led to competent actions or autonomous actions. In other words, support seeking helped the students gain confidence to attempt to implement their solutions or to accept the stressor. George stated:

> In the time that I was facing the challenges, I felt incapable because I was very confused as to why I wasn't getting what I thought I was going to get. And I felt I was just doing poor research. Then [after talking with teaching staff], I was doing the actual analysis of the data. I felt I was still competent and that I knew, oh yeah, I know why this happened or at least why I think it happened. And so I just felt confident in what I was doing.

James stated:

> It's [after talking with teaching staff] definitely relieving to know that my thoughts were good enough to write about.

Lilly also discussed an adaptive coping strategy in the interview when she said:

> The more I talk about it [with people], the more I come up with ideas.

In the cases of George, Jack, James, and Lilly, support seeking was an important behavior to proceed with the project, because they developed collective ideas to solve the problem, validated their ideas with the teaching staff, and accepted the fact that the stressor was not their fault.

However, the degrees and types of relationship actions taken for support seeking differed among the students. In particular, James, George, and Lilly actively used support seeking to negate their stress and obtain ideas. These interactions were encouraged by peers' responses and the quality of their support. However, there were differences in the students' main support sources. James stated:

> I guess my group communicated really well. We talked a lot even outside of class about things. So even about their experiments as well. We came up with a lot of different ideas for things... We liked talking about the things that were going on... so we came up with ideas for each others' experiments.

George said:

> I used my teaching staff to the fullest, like I was constantly asking questions during the lab and they would like to discuss with me what happened in their past lab experience and how they went about doing things and so that was very helpful in me organizing my thoughts and what I wanted to do proceeding with the experiment.

In contrast, Emily reported that although her personal relationship with her group members helped her feel familiar with the research equipment, it was not from talking about how to do the research or use the equipment. Instead of sharing ideas and talking about the work with her group members, she explained that she only received emotional support from her peers. Jack also received support from the professor but not from his peers. Jack stated:

> They [group members] didn't really know about what to do in this situation. They told me just to talk with professors about it.

In these two cases, a good peer relationship was not associated with academic support. It could be that their peers were not ready to support them with knowledge, time, or willingness. Additionally, the students' perceived roles as PIs and their previous practices in biology labs influenced their coping strategies, as mentioned earlier. For instance, Emily reported that her perceptions of her responsibility as a PI who was tasked to lead the zebrafish investigation prevented her from asking for more help from her group members. Emily stated:

> I just didn't want to bother them with it [research challenges]. I guess because at the end of the day it was my paper that I had to write. and wanted to be able to answer questions to my team members if they had questions, so I wanted to know enough about this topic, zebrafish, in order to be able to make sure that my investigation was going well … I didn't expect my team members to have it. I expected myself to have it.

The failure of using active support seeking seemed to be closely related to Emily's more negative views of her own competence, which she attributed to lack of lab course experience in comparison to other students, who as confirmed biology majors were taking or had completed a chemistry lab course.

Similarly, Jack did not ask other students outside his group about his research problems apart from communicating with the student from another team who provided data from a normal breeding tank. Jack said:

> In high school I had a lab class and, like, in that class the teacher didn't let me talk with other people outside of my group. So I just sort of expected that in this class too.

The regulations of his past biology class in high school influenced Jack's perception that collaboration might not be allowed in this biology class.

Both genders benefited from information seeking, problem solving, and emotion-focused support seeking, as indicated by the findings summarized in Table 6. Students of both genders claimed that they received emotional support when they talked about their problems with students who were in the same situation. Lilly stated:

> I definitely felt better about my situation because originally I felt kind of alone whenever, especially within my lab section, both my partners had data to work with.

George stated:

> It was good to know that I wasn't the only one that was experiencing difficulties with my research on my data. So it's kind of peace of mind.

In summary, students' choices of relationship actions were not only affected by their relationships with others, but also by their perceptions of their responsibility, the quality of peer responses to their requests, and their prior experiences in labs where collaboration in a group was not encouraged or structured into the expectations for lab work.

Autonomous Actions

All five students used relationship actions that influenced their autonomous actions as summarized in Figure 3, and these autonomous actions included accommodation or cognitive restructuring. Students showed a flexible adjustment to available choices and constraints. Autonomous actions were often demonstrated in the last part of the research process as students worked to understand constraints and what could be done. They realized and accepted the constraints of a course-based investigation, including time, restricted materials and equipment, and limited control over the possible causes of the fry death. Some students realized the constraints of the research through their own observation, with support from others, or both. In other words, accommodation or cognitive restructuring occurred independently, with help from others, or both. For example, Jack observed and compared the tanks and realized the constraints. Jack stated:

> In that situation, I just accepted it and wrote it in my report that it was something I couldn't really accomplish because I lacked both the resources and time to be able to do it.

In contrast, George got support to change his perception of the unexpected data. He described that there was a shifting moment when he felt relieved after communicating with teaching staff. George stated:

> The shift was just me coming to the realization that errors in science happen and that you should still acknowledge them. At first when I was thinking it was a failure, I was thinking I'm a bad scientist because this is something I did wrong. But then, after hearing from my teaching staff and my group members, it helped me to realize that the experiment not working out

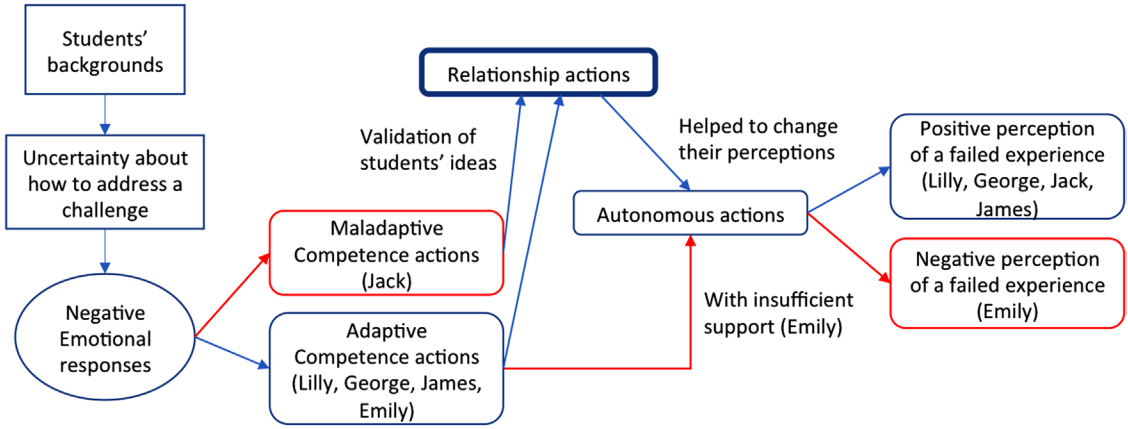


FIGURE 3. Relationships between coping strategies and perceptions of failed research.

> doesn't mean there is no value from it, that you could still get something out of it. It wasn't necessarily a failure, it just didn't match my expectations.

How students adjusted the stressor and how they perceived this experience were varied. Most students expressed "relief" while they demonstrated autonomous actions after accepting the fact that errors can occur, but some students also expressed frustration (e.g., James, Jack). James stated:

> It was frustrating because the way that I thought to solve the problem could not happen. So that was the kind of constraint there.

If frustration is related to students' stress, we can interpret that some students accepted the constraints with some stress.

The perceptions of students' failed research experiences varied, as summarized in Figure 3. Students cognitively perceived this experience as either a positive or negative experience. For instance, Lilly, George, Jack, and James cognitively reconstructed this experience as not a failure but as a valuable learning experience regardless of the obstacles. Lilly stated:

> It was imperfect. I feel if you come out from an experiment, even if it's not what you thought it was going to be, and you still learned something, then it's still beneficial, not necessarily a failure.

Additionally, these students did not attribute failure to their abilities but understood that science is not straightforward. Lilly stated:

> Real research is messy. It's not going to be straightforward answers and straightforward ways of doing things.

James also noted:

> I was very nervous, and I wasn't sure how good of an investigator I was. But then, by the end, I definitely changed, and having the failed experiment, failed data, it did not make me feel like a lesser investigator. Because I knew that there was something else happening that I did the best that I could to control it. So knowing that I did not place any blame on myself for it happening so I did not have to ever think that I was not as good of an investigator because it happened.

This quote from James illustrates a relationship between autonomy and cognitive restructuring. It highlights two features of his autonomy. First, James described that he did all he could, indicating that he felt a level of control, and he used it to control his own actions. Second, when James could not control the outcome, he did not blame himself for the outcome. Like James, Emily demonstrated autonomy, but without cognitive restructuring she believed that this experience failed, because her research goal was not achieved, and she tried but did not find the reasons. Emily stated:

> I think failure is when you set a goal at the beginning of your research and you're trying to find something. You don't have any data to go off of by the end of your research. So, I wanted to figure out what the phenotypes of this offspring would be but I didn't have offspring. So, I would say that's a failure. But then again, if I maybe could have found a reason why they didn't, then I probably wouldn't say it was as much of a failure, but I didn't find any reason why they weren't surviving. I'm just saying that was just a total failure all the way around, sadly, for me.

Emily also felt a level of control that led her to look for a reason, but she seemed to be blaming herself rather than recognizing that the problem may not have been solvable given the course constraints. These different perceptions of a failed research experience reflect the relationship between autonomy and cognitive restructuring in ways that align with their research self-efficacy after completing the project. For this study, we refer to self-efficacy according to Bandura (1997) as a belief in one's own capacity to cope with the specific problem effectively, which implies the perception of capacity to exert control and deal with the stressor.

There were other factors that a student, James, described as affecting his autonomous actions. Students' experiences outside of a course can help them accept a stressor. Because James had a successful research experience in another course, he was able to see success as well as an unexpected challenge in the research process at the same time. This experience enabled him to easily adopt cognitive restructuring regarding this failed research experience. James stated:

> [In one class,] I had a really good experiment, and one [other] class was not so good. It's okay to have a failed experiment because that happens. Just because one experiment goes well, don't expect all of them to go really well … My two classes reflect reality.

James also discussed how his maturity level related to his stress level and response. Because he was a junior, he predicted that his maturity level helped him positively respond to the challenge, as he had already been in a similar situation. James said

> I was the oldest student, of course. I just think I have a different maturity level about everything else that's happening in life. I've had enough experiences of things that didn't exactly go my way and even in college if I've already had these experiences that didn't exactly go as I planned, I kind of already know how to work through them. Whereas, if I was a first-semester freshman coming into this and having the exact same experience that I did last semester, I think that would have greatly affected my desire and my ambitions to do research.

Other Factors of Relevance

Other factors are related to personal characteristics, interests, or career paths that can affect students' responses to their research challenges. First, students' level of interest in biology or career goals can influence their responses. Emily was at the stage of exploring her interests between psychology and biology. She had not yet enrolled in a college chemistry lab. In fact, the reason for her interest in biology was to pursue a career in anesthesiology, not research. In contrast, James had already explored his interests for a while; he started in a liberal arts program and decided to change his major to biology when he became a junior. He already had developed his interests in biology and enjoyed the ambiguity of science. James stated:

> I love being in the lab and I love collecting data and looking at everything. I'm always down for learning new things. If there's ever something I don't understand, I'm always asking questions.

In contrast, Emily stated:

> I don't ever see myself going into research in biology because I think I would pull my hair out because I'd be so stressed all the time because you're going to hit obstacles and things don't work. I just want things to work. Maybe I have the skills to do it but I don't think I have the ambition to do it.

Their different ambitions may have influenced how well they valued what they learned from a failed research experience.

Other student characteristics also impacted their responses to the research challenge. For example, George expressed himself as being a goal-oriented person. His personality triggered his fear of failure. George stated:

> That was one of the things that was difficult because I was so focused on the goal of reaching conclusions that supported my hypothesis. That was something that potentially could have screwed me up. Once I didn't reach the data that I expected, I felt like I had failed.

A student's perceived difficulty in a course was related to stress levels and responses. Jack and Emily struggled with gaining new information, such as skills, advanced terms, and content knowledge, at the beginning of the course. Emily thought that she did not have enough skills and experience because of her lack of a chemistry lab course, in contrast to the other students. Because the perceived difficulty of the course content was connected to their competence, it influenced their stress levels and competent actions. Jack stated:

> It felt rather complicated because in the beginning of the year it's a lot of complicated and advanced terms and subjects and stuff and it felt a little complicated in the beginning.

Finally, how students perceived and used the suggested information differed. For instance, the teaching staff in this course explained that unexpected things often happen in the research process, and they tried to help students understand that, in science, useful evidence can emerge from mistakes. However, this message was perceived differently by different students. James, George, and Lilly described that this message helped them negate their stress. However, it seemed that it did not mediate Emily's stress, as she interpreted it on a different level. Emily stated:

> I knew it wasn't going to plummet my grade … I knew that [getting a bad grade] wasn't going to happen because I knew the professor was reasonable [because she explained this message]. I wasn't too worried about it, but I was so stressed because it's stressful to know that it's not working out and all of the other studies worked out perfectly.

Emily interpreted her experience according to her context of feeling less prepared than other students who started with more prior knowledge and experience in science labs.

Students Described Similar Learning Outcomes, but Their Feelings of Confidence Were Varied

All of the students explained that they learned about the importance of communication, the empirical nature of science, and the research process. Most of the students reported that they realized the importance of patience. James said:

> I learned that I was much more patient with myself than I thought I would be.

Additionally, students described critical thinking, problem-solving skills, the importance of asking questions, and the difficulties of dealing with animals.

Even though students valued their experiences and lessons learned, they reported different levels of confidence. James, George, Lilly, and Jack felt more confident in doing research. In contrast, Emily expressed doubt about doing future research, as she claimed to lack "ambition," but she felt a sense of accomplishment in her ability to complete the task. Regarding her research paper, Emily said:

> I guess I felt a little more accomplished that I actually had a full paper. It wasn't exactly where I wanted it to be. It was a rough draft, but it was a full paper. So I think maybe being a scientist in that biology class made me think out of the box, instead of just, you know, having an answer for everything, you have to dig for those answers.

Several aspects of their experiences when they addressed the challenges they encountered supported students' feelings of confidence. When a student recognized the completion of a difficult task, it lead to self-efficacy. Lilly stated:

> I struggle sometimes whenever I come upon a problem. I feel defeated pretty easily but it's hopeful coming upon a problem and actually having to solve it, finding a new way to think about things.

Additionally, all five students acknowledged their improved skills and strategies to handle future research problems. James said:

> That [the zebrafish module] makes me more confident now I'm doing research and I've gained those skills in analyzing things as they're happening.

Jack felt more confident, even though he felt that there would always be something he would not know. The students also developed beliefs that they can modify and control the environment by using their skills, resources, and effort. Jack stated:

> If it does mess up, I don't think next time I'd be completely lost, and I could actually make it work just by examining why it didn't work the first time.

Students felt that they could manage research challenges better in the future and could understand the iterative research processes in science.

Among the five cases, Emily showed relatively lower research self-efficacy, meaning that she lacked confidence in her ability to tackle research problems. She gave several reasons. First, even though she was good at biology in high school, she felt less competent compared with other peers and expressed a perceived difficulty from not having taken a chemistry course in which others were learning to use lab equipment. In fact, her only experience with biology was in high school. Also, she expressed feeling a burden as a PI because, as mentioned earlier, she thought that she needed to inform her peers and was supposed to control the research process independently. She reported feeling lack of competence when she took some responsibility for the fry deaths. Emily said:

> I did not get the results that I wanted. It was not working out at all. That bothers me because I think I had the only tank that was not getting fry [at first]. Every other tank at least had one and I felt I was doing something wrong personally because why is it that our team is not getting anything? I wouldn't say it was all on me, but I definitely take some of the responsibility for it.

With her perceived difficulty, her competence was not promoted or validated by others, because she only received emotional and not informational support from peers who were more experienced than she was with the lab equipment. Emily stated:

> I didn't talk to anyone. I would say no one with higher authority. If I talked to anybody they were from another team with a different tank, just to see if they were having maybe some problems that they could give some information on. But other than that, I didn't really talk to anybody about it.

Unlike the other students, she did not find a chance to validate her ideas or abilities with others, and she worked to resolve the problems mostly by herself. Emily reflected:

> I learned something from being an investigator and having to make the decisions about what was going to happen with the tank. But I don't think I learned enough to basically do that again and be more effective than when I was the first time.

Emily seems to attribute her low research self-efficacy to her feeling that she had not gained enough abilities or competence to conduct research in biology.

Multiple factors were associated with Emily's negative perception of this experience and research self-efficacy. Eventually, she gave reasons for switching her major to psychology when she stated:

> I am just not sure I am interested in it enough to want to do that … I like researching people, which is why I'm [now] in psychology.

She further explained:

> Maybe in some majors here at college they push you a little harder because they need to weed people out because a lot of people try to go for those things. And biology happens to be one of those. I just didn't get a great foundation in biology because I only took a few years of it [early] in high school. It's better to be honest with yourself about knowing I'm not good at this and I can't handle this kind of failure every time. So I need to find something that's more for me.

If Emily had received better training or some tutoring, she may have developed more skills and competence, which could have given her confidence and increased her research self-efficacy. We also do not know for certain, but it could be that her lack of experience and confidence influenced her isolation and lack of research self-efficacy as she coped with failures.

DISCUSSION

How a Failed Research Experience Impacted Students' Feelings as Investigators

Even though the five student participants in this case study had different characteristics, all reported their first emotional reactions to research obstacles as being negative. These negative emotions resulted from aspects of the failure experienced, including uncertainty about grades, not being sure of their ability to complete their task, and worry about being judged negatively by others or letting others down. These types of social and outcome-focused emotions are similar to those reported by

England *et al.* (2017), who studied anxiety among undergraduate students in three introductory biology courses. Anxiety is a negative emotion when students encounter failure and are not sure of their competence to control the results (Pekrun *et al.*, 2007). In our case study, some students also reported being worried about not having the correct answer, which echoes a report by Radoff *et al*. (2019), who examined changes in one undergraduate student's emotions as she worked through weekly problem sets in physics that emphasized good reasoning versus correct answers. Similar to reports from other academic contexts, this type of failure-related anxiety might reduce interest and motivation, but it could also strengthen motivation to invest effort to avoid failure (Pekrun, 2017). In this particular lab, frequent student testing on how to employ protocols (and why) gave feedback to help the students judge for themselves how adequately prepared they were on the expected techniques. These tests provided practice in providing clear reasoning about how to gather and use data to answer open-ended research problems that had no single right answer. In fact, this study identified a participant who had initially shut down and how he began to feel more confident after he used his negative emotions to motivate his work when he received positive feedback on a test.

According to Skinner *et al.* (2014), emotions can inform researchers and instructors of students' levels of participation, coping, and required support, so we analyzed the negative emotions of relevance to the research process surrounding the failure experience in order to understand more deeply the types of support that might be needed. Self-doubt and nervousness when resolving a research problem is inherent to the process of science. Just as a scientist would feel, these students felt confused about why the results were not what was expected. They were initially uncertain about what to do, and they doubted their own knowledge and ideas. They felt stress when they "had no idea whether their idea was right or wrong," so the case study students worried about the open-ended nature of the research. However, negative emotions cannot always be avoided, and acting on negative emotions can be beneficial to research. Like scientists, some reported as pleasurable their examples of uncertainty and surprise. They confronted their frustration about obstacles with curiosity and ideas about how to address the problems. When they were not sure what to do, they did not give up. They took control, and they employed strategies to avoid being overwhelmed. For example, the anxiety James felt positively influenced his learning, because the research challenge encouraged him to more actively communicate with his group members. Even though frustration remained, because the time and resource constraints prevented them from actually solving the problem, the failure experience and lab environment allowed students to develop and practice valuable coping strategies.

The five students had rarely experienced the need to come up with their own ideas in labs, so this was daunting, as they were accustomed to lab courses in which everyone was expected to get the right answer. With their prior experience being limited to traditional structured labs, they felt insecure when suddenly there could be many different answers. However, we also found that the intensity or degree of negative emotions varied. In other words, how students appraised the meaning of their research failures as stressful events reflected how aspects of their basic needs were met according to SDT. In this study, all five students felt frustrated, but only those who were most worried about the difficulty of the class because they entered the class with less background knowledge reported feeling overwhelmed about deciding how to confront their research obstacles. Feeling overwhelmed is an activity-focused emotion, because it involves uncertainty in not knowing what to do. Their intensified negative emotional response influenced their ways of coping. Their resources and the lab environment influenced how well they regulated the negative emotions with coping strategies, which is important, because emotional recovery is related to re-engagement in academic tasks (Skinner *et al.*, 2014).

The Students Employed Coping Strategies Aligned with SDT to Address Research Challenges

After the students initially showed anxiety, they were influenced by experiencing additional emotional reactions to failure including anxiety, uncertainty, confusion, frustration, stress, or worry that they addressed with various coping strategies that aligned with SDT (Figure 1). All five student participants primarily adopted adaptive coping strategies, such as competent problem solving, support seeking, and accommodation (or cognitive restructuring) in agreement with reports by Gin *et al.* (2018) and Skinner *et al.* (2003). However, each student showed a unique process of handling research challenges based on personal circumstances and characteristics, because the coping process is complicated and dynamic due to intra-individual and interindividual variability (Lazarus and Folkman, 1984). Many factors reported in our findings, such as feedback, social interactions, resources, emotional intensity of the perceived threat, and previously adopted coping strategies, can affect a student's coping process. These factors influenced students' coping processes in ways that were interrelated and multidimensional, which agrees with reports by Gin *et al.* (2018) and Hilliard *et al.* (2020). The students' emotional demands associated with failure changed as they applied adaptive coping mechanisms. Our findings confirm that adaptive coping strategies contribute to the resolution of the problem or uncertainty (Hilliard *et al.*, 2020).

The value of instructor support in our findings has been identified in other studies, such as Schussler *et al.* (2021). When students appraise high supportive instructions, their levels of anxiety are diminished, because instructors' feedback alleviates student anxiety and helps them to be more persistent (England *et al.*, 2017; Schussler *et al.*, 2021). This was confirmed by findings from this study when adaptive coping behaviors provided feelings of relief after students received social support, including from instructors. The sharing of personal experiences (e.g., experiences related to the nature of science or failure) also reported by Gin *et al.* (2018) and Goldman and Goodboy (2014) and instructor immediacy as reported by Allen *et al.* (2006) were components that helped students positively accommodate the stressor after getting immediate responses or listening to similar experiences from peers or teaching staff. The teaching staff, including undergraduate peer leaders, TAs, and the course director, need to be equipped to empathize with the negative emotions and to work respectfully with the students to resolve negative emotional experiences. Indeed, it is important to recognize that even simple affirmation from a teaching staff member can curtail the process of considering several alternative possibilities, as was the case for George, who mentioned a

conversation with an instructor as his reason to stick with his initial research idea, even though his original study resulted in a large error measurement. Instead of giving answers or telling students which of several options they are considering is the best one, collaborative decisions can be structured to further lead students to use their autonomy to accommodate constraints in their research plans and to reflect on their own experiences and further develop their coping processes. This would be in agreement with reports that instructors who can validate students' negative emotions to demanding tasks and provide emotional and constructive feedback with warmth and caring encourage students to recover their interests and motivation and to use adaptive coping strategies, including social, academic, and personal resources (Skinner *et al.*, 2014).

SDT emphasizes the importance of a supportive social context, because the learning context can either support or thwart students' psychological needs. In this study, feelings of relatedness to others within the social context of the lab helped individuals acquire emotional and informational support. However, we found no evidence that these needs were thwarted, as no student reported prolonged feelings of helplessness. Even in the case of Jack, who experienced a depressive episode, his relationship actions helped him manage the stress over time. Time was set aside in the lecture for students from different lab sections to share and discuss their research difficulties with others who were in a similar situation allowed students to receive emotional and information support. Such coping strategies affect students' emotional recovery and re-engagement in academic tasks through behavioral actions that modify cognitive and affective responses (Skinner and Wellborn, 1997). Our findings also align with those of Reeve (2009), who found that the learning context increases autonomous motivations if it promotes student's feelings of efficacy by providing choices to support their autonomy and connectedness. After receiving support, students in this study felt more competent and understood the nature of the stressor.

Some students (e.g., George, James) stated that they perceived the learning context as being an autonomy-supportive environment, which is a finding aligned with reports that a supportive environment can increase levels of satisfying learning experiences, engagement, and performance (Jang *et al.*, 2009). The aspects of autonomy-supportive practices in the lab environment for this case study, according to Reeve (2009), included opportunities for students to autonomously determine how to redesign their research questions, conduct experiments, and write their final papers by using multiple resources. In summary, when all three components of SDT were supported, students in this study manifested adaptive coping strategies to confront challenges. All but one retained an interest in biology. In particular, social relationships played a key role in supporting students' psychological needs.

Divergent Patterns of Relationships Influenced Some Coping Behaviors

In addition to the coping strategies used by all students, we also found divergent patterns of coping behaviors and self-efficacy, in particular for Emily and Jack. In terms of their SDT competence, relatedness, and autonomy, strategies were employed to address the abovementioned emotions in the following ways. We found that concurrent or prior lab skills and training impacted how well they cognitively reconstructed their failed experience, which seemed to impact their research self-efficacy. In addition to starting out differently from the others in their perceived competence to handle the stressor, Emily and Jack were different in terms of their peers' responses, the quality of support they received, their perceptions of collaboration in their investigative role, their relative lack of previous lab training, their experiences outside this biology course, and their ambitions and interests in biology.

Active coping including social support to address a stressor has been reported to have a positive relationship to retention with the major (Shields, 2001). However, the varying levels of social support in this study influenced the students' self-efficacy and persistence and their levels and types of support seeking. Jack and Emily initially did not receive effective problem-focused support from peers, whereas James, George, and Lilly, who demonstrated only adaptive behavior, received supportive problem-focused help from peers. This is similar to a report by Altermatt and Broady (2009), who found that when fourth to sixth graders received frequent support from their peers, they reported fewer maladaptive behaviors to failure. This is in contrast to learned helpless maladaptive behavior that was anticipated with off-task talk, when they discounted their failure, and when their peers negatively refereed the task. Symeonides and Childs (2015) similarly found that social interactions allowed students to receive emotional support and to understand peers' struggles in an online course. In this sense, our findings confirm that students' coping strategies and emotional behavior are promoted by effective interpersonal interactions and support. In addition, Jack held a different expectation about collaboration from high school based on his previous structured lab experiences, so both demonstrated a need to develop new coping strategies associated with relatedness. When Jack perceived the stress as a threat to his competence, he showed "escape" as a maladaptive coping behavior. Jack's experience aligns with the research by Cooper *et al.* (2020), in that getting support and feedback from social relationships alleviated depression when experiencing failure in research. When Jack received constructive feedback on his competence from teaching staff, he gained confidence and re-engaged to address his failed research problem. In this sense, interpersonal support played a critical role related to competence. Thus, his personal expectations based on previous lab experience and the feedback he received influenced the types of relationship actions, the persons he sought out for help, and the degree to which he adopted relationship actions.

Our findings highlight the need to inform future work with reports that students' competence needs should be satisfied, as competence can promote motivation (Schunk and Zimmerman, 2006). Compared with the other students, Emily showed relatively high anxiety about her circumstance of doing biology lab research, mainly due to her lack of lab training compared with the others. Emily's competent use of information-seeking strategies is consistent with other reports that anxiety can motivate learning and is not always negatively related to academic achievement (Pekrun, 2006; Respondek *et al.*, 2017). Emily worked hard to demonstrate competent information-seeking strategies independently, and she received relatively less support from peers or teaching staff. But this led her not to validate her ideas and may have interfered with her competence to solve the problems, making her work more

difficult, which could have influenced her negative perception of the failed research experience and resulted in low research self-efficacy. Emily's burden as PI stemmed from feeling the need to be prepared to answer questions about the zebrafish project from her peers. This is in agreement with reports about the fear of negative evaluation in a social situation (Ryan, 2001; Cooper *et al.*, 2020). In spite of her competence with finding information and writing a research paper, she acknowledged that others were more proficient with lab work, and she felt unsure about her ability and not motivated to conduct biology research in the future. Her decision to leave the biology major is consistent with England *et al.*'s (2017) report on student retainment risks. Emily conceptualized research in biology as involving high efforts and the risk of costly failure, so this may be why she decided to leave biology. However, our findings question whether the problem is anxiety, which is associated with an uncertain outcome, as Jack also experienced severe anxiety (his depressive episode), and yet he felt that the experience had confirmed his competence for doing research. One difference between Jack and Emily was in the quality of problem-focused support received through relationships and Emily's perceptions of how her peers might judge her. There is a need to help students to manage their anxiety when they face the unknown by focusing more on helping them learn how to address and feel about emotions, as reported by Radoff *et al.* (2019). Could her ambition to do research have been motivated by additional training and a more collaborative approach to addressing her research problem, or was her interest in people and psychology pulling her away from a biological sciences career? Within our study confines, findings support the idea that competence is a key component to having a sense of control over the stressor to be able to cope with a problem effectively (Bandura, 1997). A more positive outcome for Emily could have involved more problem-focused relationship actions that would have developed her competence, rather than leaving her to work so hard independently with concerns about judgments by others, given her relatively weaker prior lab experience.

Emily also attributed the failure as her own fault, which others report can negatively influence motivation (Graham and Williams, 2009), and this could have influenced her decision not to risk facing future failure in the biology major. Other students did not attribute failure to themselves. Gender differences in postfailure interactions have also been reported by others who found female students' interactions to be more supportive than male students (Altermatt, 2007), but Table 6 shows no patterns consistent with gender differences in our case study. Considering that Emily is our only student participant from a historically marginalized racial group, we must point out that race did not ever come up in her reported experiences as salient. While individual narratives can never be attributed solely to race, and this is definitely not the focus of our current study, there remains a need for experiences with failure to be investigated in light of other studies that address the experiences of Black students. In summary, Emily decided to major in psychology and not in biology, because she found the research in biology to be quite difficult and blamed herself for the failure experience. Other students who built more academically supportive relationships demonstrated the autonomy to alleviate their stressors, they gained problem-solving ideas, and they accommodated the messy and ambiguous nature of science in a way that continued to interest them in the biology major.

Learning or Knowledge That Students Perceived Gaining or Could Have Gained from a Failed Research Experience

Although it has been reported that helplessness or anxiety and other generally negative emotions can hinder students' learning (Pekrun *et al.*, 2007), students in this case study recognized valuable learning outcomes upon completing their research projects. All five students felt a sense of accomplishment from the research paper they wrote. They valued learning how to use the lab equipment, being an investigator and having to make the decisions, and understanding the empirical nature of science from their failed research experiences. The present study provides support for the value of failure to show uncertainty about research in an undergraduate biology laboratory course. However, only some reported learning about how to communicate with their group members about their uncertainty more actively, and only four of the five reported feelings of confidence for doing open-ended research in the future. In this case study, collaboration should have been more explicitly addressed, that is, by discussing how to take responsibility as a PI by distributing the work and planning team discussion of research ideas, such as by talking with other people outside the research team. This would address our finding that past biology labs have influenced the perception that collaboration might not be allowed, which is counter to how research in science advances through structured collaboration. It seems appropriate to provide more open-ended research opportunities in future labs in spite of the likely chances of failure in order to try out recommendations for supporting students in managing their stress from Peppercorn (2018) and studies in other disciplines on how to guide students to practice collaboration and other adaptive coping strategies (Pekrun *et al.*, 2007).

Limitations

There are several limitations to this study. First, according to Nederhof (1985), the self-reported data from interviews may make students more likely to report positive coping strategies as a desirable response, either to paint themselves in a more positive light or to present a more positive experience to the interviewer (social desirability bias). A second pitfall is that students may not have been candid if they felt that their interview data would be used by individuals affiliated with the course. To help alleviate this bias, according to a protocol approved by Purdue's IRB, the first author and interviewer explained that their identity and responses would remain anonymous and their names kept strictly confidential. Specifically, interviews were recorded and transcribed so that anyone who taught or assigned grades would only see the transcript with the name replaced for data analysis after the participant received a final grade in the course. Third, the findings were restricted to five participants. By compiling each student's coping processes, this study has captured many, but certainly not all of the coping strategies, responses, and emotions that students may experience due to the complexity of emotions and individual circumstances.

In terms of research design, students in this study were interviewed about their initial expectations or emotions after

finishing their research. The recalled data might not have accurately captured students' initial emotions, conditions, or thoughts about their failed research experiences. Because this study focused on analyzing students' perspectives on and coping strategies for failure in a biology laboratory course, relationships between instruction and learning outcomes were not primarily explored. Additionally, this study did not explicitly examine how racial or gender identity might have influenced the learning process, interactions with others, and outcomes compared with other students. Considering these limitations, we feel our findings do show examples of coping strategies for managing negative emotions from failed research to help advance future studies and to motivate teaching approaches for labs that introduce undergraduate students to research experiences where there is no predetermined successful outcome. However, we recognize that it is necessary to further investigate how students' backgrounds and emotions affect their learning processes and outcomes from failed research experiences.

CONCLUSION AND IMPLICATIONS

The students in this study were concerned about judgment from peers and their grades, and not all students collaborated effectively with peers as they dealt with the negative emotions they faced during their failure experiences. However, in this study, the instructors framed the course as a learning experience regardless of whether success with the zebrafish population investigation was reached. This may have targeted meta-affective learning, which we know helps students to build self-efficacy and manage anxiety (Radoff *et al.*, 2019). Because struggles and iteration are meaningful in student learning and are inevitable in open-ended research (Gin *et al.*, 2018), it is crucial for instructors to reflect on how to evaluate student collaboration and other accomplishments in biology lab courses regardless of their research outcomes. Evaluations that can reduce competition, work toward standards that include collaboration and meta-affective learning goals (Radoff *et al.*, 2019), and provide informative and cognitive feedback on students' learning processes could build students' intrinsic motivation (Bruning *et al.*, 2001). Thus, it is necessary to define criteria that embrace students' learning processes and desired outcomes while they develop and practice competence for solving research challenges. Because students' attempts and ideas to solve research obstacles are bound by the constraints of a course-based investigation, a system for evaluation must consider these constraints and encourage students to reflect on their learning processes, including learning how to cope and how to collaborate more effectively. More research is needed on the development of assessments that can support and measure learning outcomes, including meta-affective learning to promote student competence for addressing research obstacles in biology laboratory courses.

Personal relationships played a mediating role in helping students to frame their failed research situation differently to manage their stress and anxiety. The outcomes of experiencing negative emotions were high self-efficacy for four students and departure from biology for one student, and this was mediated by their coping behaviors involving interpersonal relations and academic competence. Although all students expressed negative emotions, the varying degrees and extents of perceived emotions should be acknowledged and understood. Thus, addressing the factors that influenced the intensity of negative emotions, such as prior knowledge and lab experiences, perceived difficulty, and levels of anxiety about conducting open-ended research, can inform support targeting students' specific needs related to competence, relatedness, and autonomy. Because students have different levels of interpersonal communication and different expectations for the lab based on their prior experiences, it is especially important to create a safe, supportive, and collaborative environment in an introductory lab course to enhance students' feelings of relatedness to make sure that each one receives sufficient academic and emotional support from others, as reported by Schussler *et al.* (2021). It is important to acknowledge that one instructional experience (sharing one's previous failed research experiences with others) may not alleviate all students' emotional difficulties and change their negative perceptions of failed research experiences. Those who express negative emotions or experience failure should be supported in various ways that address their needs in terms of competence, relationship, and autonomy. Given our history of traditional labs in which the teaching staff have been authorities who make things work, it may be necessary for labs to schedule more student discussion times for suggestions about research challenges, as was done periodically during lab lecture times during this study. Instructors can explicitly plan how to provide a supporting environment where the student investigators can develop their autonomy and coping strategies and not just defer to the teaching staff.

In conclusion, the present study shows how students dealt with negative emotions when they faced uncertainty about research due to a failure experience in an undergraduate biology laboratory course. Our findings provide support for the value of showing and sharing uncertainty. Also, all students expressed negative emotions, but the varying degrees and extents of perceived emotions should be acknowledged and understood. Thus, students' personal contexts should be considered when embracing failure as a normal part of scientific practice to avoid trivializing an individual student's complex emotional demands associated with failure. Interventions are needed to reaffirm for students how to capitalize on the associated feelings of anxiety and confusion to promote the development of competence, relationships, and autonomy as integral to scientific discovery. Findings confirm the need to focus on finding ways to help students recognize and more comfortably position themselves as uncertain about research problems. Future research could explore interventions that help students practice adaptive coping strategies in undergraduate biology labs, informed by Watkins *et al.* (2018) and experts in other disciplines (Peppercorn, 2018). Instead of a failure to discover, the emotional experience of failed research is an opportunity for learning.

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