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Investigating Transformative Experience and Community-Engaged Learning in STEM to Bolster Student Connection, Recognition, and Application of Science Ideas

A Dissertation submitted in partial satisfaction of the requirements
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in

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by

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The dissertation of Makenna May Martin is approved, and it is acceptable in quality and form for publication on microfilm and electronically.

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ABSTRACT OF THE DISSERTATION

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by

Makenna May Martin

Doctor of Philosophy in Math and Science Education

University of California San Diego, 2023
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This dissertation project designed, implemented, and measured the efficacy of Transformative Experience teaching methods in Community-Engaged contexts to help students connect with and apply their scientific knowledge in their daily lives. The Transformative Experience framework connects class ideas to everyday experiences by scaffolding students' personal connections to the science content. These connections help learners overcome emotional and motivational barriers to learning and inspire students to recognize the ways they can use science in their day-to-day lives. Community-engaged learning is a broader category of hands-on activities in which students learn how course content is related to the local community and undertake authentic practices to help serve a community goal.

Both methodologies were designed to help students bridge the divide between "coursework" and "real life" that often prevents students from transferring the ideas learned in class to relevant real-world situations. This is especially important as our society increasingly must make important decisions about science-related phenomena, such as personal health choices, voting, or environmental decisions. Although these research-based teaching strategies have demonstrated efficacy in promoting students' perceptions of their connections to course content and the application of their knowledge in the real world, they have yet to be used in tandem within the context of undergraduate education. This study fills a gap in the literature, while exploring methodologies that have been shown to promote positive student outcomes, particularly in underserved populations participating in STEM such as women, first-generation students, and minoritized groups.

Using a mixed-methods observational study approach, student surveys and written reflective assignments provided quantitative and qualitative evidence for this project. Results demonstrated that combining these methods is effective in fostering students' recognition and application of science ideas in their daily lives. The results indicated that these methods are also fruitful in promoting personal connections. However, the project was unsuccessful in promoting social connections to the science content. The limitations for promoting social connections are discussed, with recommendations for reflection activities and hands-on activities for enhancing student engagement with the communal and social value of STEM.

Chapter 1 INTRODUCTION

Scientific literacy, and particularly the application of science ideas, is important in many ways: applied scientific knowledge can help people make strategic, deliberate choices about voting and political issues, medical decisions, and environmental choices, among others (Sharon & Baram-Tsabari, 2020). Acknowledging this, the National Academies (2016) and National Research Council (2012) have issued reports advocating that education should aim to promote students to be future citizens who can relate their classroom knowledge to their everyday lives. The reports speak to the importance of preparing students to think critically about daily decisions, personal choices, and detect claims containing illogical or fallacious conclusions. These skills are particularly important in today's climate of misinformation. Although students learn about science ideas such as immunity and environmental science in the K-12+ school setting, they often fail to apply this information when faced with real-world dilemmas such as anti-vaccine or climate change conspiracy theories (Sharon & Baram-Tsabari, 2020). The lack of translation between science ideas and daily life has led to a public that is not scientifically literate. For example, even though it is a widely accepted fact in the scientific community, only about half of Americans believe that climate change is impacted by human activity (Leiserowitz et al., 2013).

This inability to translate science to daily life indicates that traditional science instruction is failing to move beyond the walls of the classroom. In fact, prior research has shown that students often fail to perceive or appreciate the value of the ideas they have learned in class for their daily lives on their own (Cobern & Aikenhead, 1997). Even when teachers attempt to promote these kinds of connections, they often fail because students cannot relate to the examples offered and students experience a strong divide between the culture of "classroom knowledge" and "real life" (Irish & Kang, 2018). Facilitating the connection to students' daily lives is often difficult for educators because it requires skills that lie outside of curriculum guidelines, such as drawing on culturally relevant examples and making in-the-moment decisions and responses to student questions or examples. Thus, teachers are underprepared to facilitate the transfer of science knowledge and students are unlikely to make these connections on their own.

The lack of transfer of science ideas to the real world is not only unfortunate for the deficit to students' knowledge, but it also increases the divide between "science" and "daily life" possibly serving as a barrier to students' motivation and interest in pursuing STEM fields (Brown et al., 2015). Groups of people, with diverse backgrounds and cultural connections, have varied interests and values and thus are motivated in different ways (Hulleman et al., 2017). Students who are first in their families to attend college, or *first generation students,* students belonging to minoritized groups, and women in STEM often have greater interest in values oriented towards community (Boucher et al., 2017). However, the culture of formal education and STEM is typically aligned with one set of values: the individual-focused goals consistent with the cultural values of the historical majority of upper-class, white, male students and professors of higher education in the United States. Thus, for students with diverse backgrounds, there is a *cultural mismatch,* leading them to feel less connected to and motivated by the traditional goals of STEM (Casad et al., 2018; Cole & Espinoza, 2008; Stephens et al., 2012). As a result, this group of students experience lesser interest and greater difficulty in the academic setting, consequently impacting their performance and persistence in STEM fields (Stephens et al., 2012).

However, there is evidence that easing these perceived cultural mismatches can be achieved when students are guided to reflect upon the ways that STEM *does* align with their social and cultural values (e.g., Estrada et al., 2016; Estrada et al., 2018; Harackiewicz et al., 2016; Jackson et al., 2016) or by incorporating connections to community and society in STEM education materials (e.g., Zambrano et al., 2020). Furthermore, fostering personal relevance can improve every student's interest in STEM, course engagement, and course performance (e.g., Estrada et al., 2018; Hulleman et al., 2017; Tibbetts, et al., 2016). Bolstering community connections in STEM is not only a benefit to all students, but also may be particularly helpful to underrepresented groups in STEM. When STEM fails to foster these real-world and community connections, students have limited access to applicable knowledge that could help them in their daily lives and they are alienated rather than motivated by science education that incorporates connection to the real world, community, and society.

There are two distinct facets of this problem: first, scaffolding real-world *application* of science ideas and, second, fostering personal and communal *connections* to science content.

1. Scaffold use of science ideas in daily life: Students often fail to take advantage of the ideas they learn in class. Traditional instruction does not support the real-world application of the science ideas learned in STEM classes. Students need to have scaffolding that not only highlights the connections between science ideas and daily life but also motivates their application of these ideas.
2. Foster personal and social connections to science content: There are very few opportunities for STEM students to meaningfully engage with their personal and communal connections to STEM ideas. As a result, they perceive a separation between "science" and "real life" or "community" contributing to the cultural mismatch experienced by underrepresented groups in STEM. Promoting these connections in

STEM can offer solutions to the first aspect of the problem by providing increased motivation for students to apply classroom knowledge in their own lives.

This research project sought to address these issues by implementing a research-based pedagogy called *transformative experience* combined with *community-engaged* learning activities. Together these educational experiences can address two problematic issues in traditional STEM teaching methods: unapplied student knowledge and lack of personal and social connections in STEM learning. This project offers an important topic of study because it has the potential to enhance student engagement and motivation, especially among underrepresented groups in STEM. These strategies have been individually observed to enhance learning and other beneficial outcomes for students and society, implementing them in tandem has the power to enhance these outcomes while filling an important gap in the literature. The research questions are as follows:

1. How can *community-engaged* and *transformative experience* activities be used to foster the recognition and application of science ideas in daily life?
2. How does *community-engaged* experience in STEM impact students' personal and social connections to science ideas?
    a. Do different kinds of students make different connections?

The *transformative experience* framework is a research-based education framework based on Dewey (1986) that highlights the importance of using strategies to connect to learners' everyday experiences (Pugh, 2011). Through this teaching strategy educators scaffold students' personal connections to the science content; these connections helping learners overcome emotional and motivational barriers to learning as well as helping students to recognize the science in their daily lives (Heddy & Sinatra, 2013; Pugh, 2020; Pugh et al., 2017). By removing these barriers, student engagement and performance is enhanced. Prior studies have shown that using a transformative experience framework in science education promoted personal relevance, positive affect, and conceptual change in students towards more complex views of scientific ideas (Heddy & Sinatra, 2012, 2013; Pugh et al., 2017). These benefits also allowed students to transfer their scientific knowledge outside of the classroom and perceive science ideas in their daily lives (Heddy & Sinatra, 2012; Pugh et al., 2017; Pugh et al., 2010).

Because of its focus on personal connections, the transformative experience framework is particularly relevant to service learning (Pugh, 2020). *Community-engaged learning* and *service learning* are learning experiences that are generally defined as academically rigorous activities, or more prolonged experiences, performing acts of service to the local community that are explicitly linked to curriculum objectives (Strage, 2000). This kind of community-focused learning has demonstrated evidence that it could further the types of benefits seen in transformative experience education. Participating in service learning activities has been shown to enhance student engagement with course content and increase performance, even in large enrollment classes (Markus et al., 1993; Strage, 2000; Warren, 2012). Service learning experiences also show lasting impacts on students' social concerns and responsibility (Warren, 2012), including pro-social (benefiting others, community, or society) attitudes and behaviors (MacFall, 2012). Thus, there is evidence that transformative experience combined with service learning can become a vehicle to motivate students, particularly minoritized groups, in STEM by promoting personal and social connections to STEM material to foster interest and motivation.

However, even though there are many potential benefits for students, there are few opportunities for community-engaged learning in STEM (Woodley et al., 2019) and there has been limited research in the area of STEM service learning. Service learning programs in fields outside of STEM have made use of the transformative experience framework (e.g., Hullender, 2015; Kiely, 2005). STEM education at the K-12 (e.g., Girod et al., 2010; Pugh et al., 2009, 2010, Pugh et al., 2017) and college-level STEM (e.g., Heddy & Sinatra, 2012, 2013) has effectively employed and studied transformative experience activities. Yet, a gap remains on *service learning* or c*ommunity engaged learning* in STEM specifically (e.g., Reynolds & Ahern-Dodson, 2010), and none seems to have employed transformative experience ideas in their design. This is unfortunate, as the transformative experience framework suggests community contexts are particularly appropriate venues to promote transformative learning (Pugh, 2020). So, not only is there a gap in the literature regarding this overlap, but the fitting combination of community-engaged learning and the transformative experience pedagogical framework have not been realized.

The study linked the STEM transformative experience literature with the service learning transformative experience literature and demonstrated the use of community activities in college-level STEM courses. The theoretical foundations of the study and prior work in relevant fields are explained in more detail in the following chapter.

Chapter 2 LITERATURE REVIEW AND THEORETICAL BACKGROUND

There are two distinct aspects of this thesis: scaffolding real-world *application* of science ideas and, second, fostering personal and communal *connections* to the science content. This chapter begins with a discussion of the first strand, then expands upon the second, and finally explains the ways in which these two aspects are connected.

Scaffolding recognition and use of science ideas in daily life

As reviewed in the previous chapter, the importance of applying knowledge learned in class has long been recognized by practitioners, researchers, and philosophers. In fact, "much of the financial and human investment in education has been justified on the grounds that formal education helps inculcate general skills that transfer beyond the world of academia and thus help students become more productive members of society" (Barnett & Ceci, 2002, p. 613). However, this transfer often fails to materialize as students tend to experience a sharp divide between "classroom" and "real life" that hinders their ability to translate scholarly ideas into their daily lives (Cobern & Aikenhead, 1997; Irish & Kang, 2018).

Dewey's *aesthetic experience* is one framework that has been adapted in education research to design activities that have the potential to cross this divide to help students use their classroom knowledge in their own lives. Dewey (1986) describes the importance of having rich, meaningful experiences that can expand our perception and thereby impact our view of the world. In writing about art, Dewey explains that when we engage with the arts, such as in viewing paintings or watching a play, we can begin to appreciate new aspects of the world (Dewey, 1986; Pugh, 2020). For example, art can help us to appreciate the mundane, such as in Andy Warhol's artistic impressions of everyday objects like soup cans and coke bottles, or in understanding different experiences or ways of thinking by watching a narrative play about someone else's life. Dewey explains that these kinds of experiences allow us to perceive new aspects of our environment that we would not have been attuned to before, thereby transforming our view and our relationship with the world around us. By incorporating this framework into science education, we can help students bridge course work and real "life" and we accomplish this by designing classroom experiences that allow students to perceive science ideas in their daily lives.

One education framework that has sought to operationalize Dewey's (1938) ideas of aesthetic experience and transformative learning, combined with theories of value and interest (e.g., Hidi & Renninger, 2006; Wigfield & Eccles, 1992), is the *transformative experience* framework (Pugh, 2011, 2020; Pugh et al., 2009, 2010). Central to this construct is the goal of helping students apply and value their course knowledge in their everyday experiences. A transformative experience has three integrated characteristics: *motivated use* describes the way in which a learner comes to apply their knowledge in daily life (even if they don't *have* to do so), *expansion of perception* where the student can use their knowledge to expand their view of real world phenomena, and *experiential value* where the student values their knowledge as a useful tool (Figure 1; Garner et al., 2016; Pugh, 2011).

For example, knowledge is transformative when students learn about the physics of weather in class and are then able to perceive and value new information about clouds or other weather events in their daily lives. Their knowledge is transformative because it helps them to perceive new insights and make inferences about the physical characteristics that brought about this weather. Observing the weather does not *necessitate* applying their classroom ideas, but the student does so because this new way of seeing the weather is both interesting to the student, as well as useful, providing them with the ability to predict or infer more information about future weather or other phenomena in the real world. In transformative experience, knowledge construction is less about the ideas themselves, but rather the potential of the ideas to enrich students' daily lives (Pugh, 2011). As such, it is a particularly appropriate framework for helping students to act upon their science knowledge.

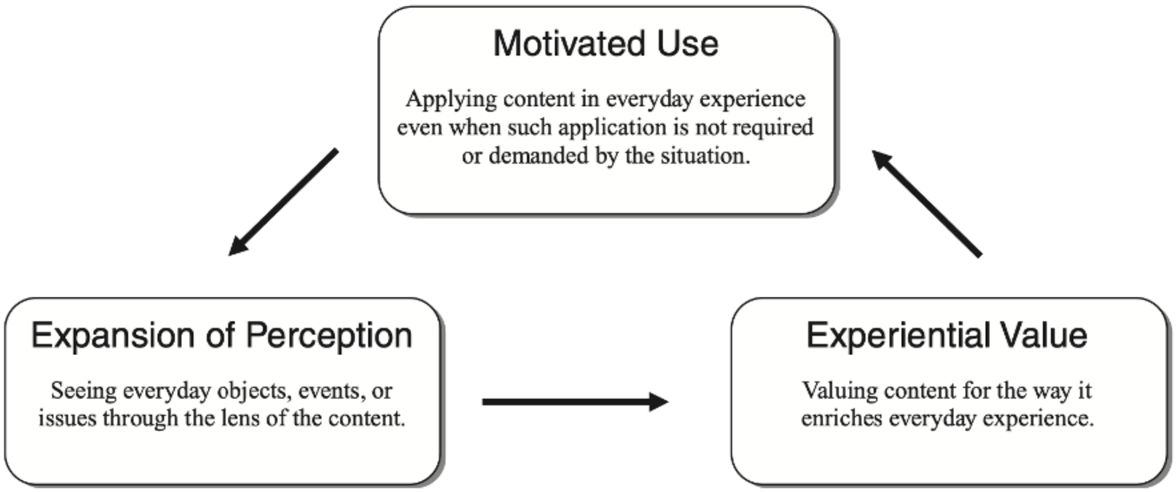

Figure 1. Three Characteristics of a Transformative Experience

Applying transformative experience in science education requires educators to scaffold curriculum in ways that connect the content to learners' everyday experiences and help them reflect on their own knowledge. According to the Teaching for Transformative Experience in Science model, to achieve a transformative experience, a learner must be provided with opportunities for guided engagement, to make connections to their own life, and to engage in reflection upon their conceptual knowledge (Pugh, 2020; Pugh et al., 2010; Pugh et al., 2017). Teaching for Transformative Experience in Science suggests three essential classroom practices that can support these opportunities and assist students in undergoing transformative experiences: *framing content as ideas*, *scaffolding re-seeing*, and *modeling transformative experience*s.

Framing content as ideas is a strategy that builds upon prior research about how the intentional selection and introduction of concepts can help students orient themselves in ways that assist their understanding and engagement with the material. Framing occurs when an educator uses particular moves in speech, actions, or writing, to focus students' attention on particular aspects of new ideas being introduced (Engle et al., 2011). Typically, educators use framing techniques to inform students about the structure or purpose of activities, to help them understand which aspects of the lesson are the most important or salient. Effective framing has been shown to enhance students' ability to transfer their knowledge to new environments (Engle et al., 2011). In *framing content as ideas,* educators intentionally introduce new concepts as possible lenses or ways of seeing the world that can expand students' perspectives (Pugh et al., 2017). Educators present ideas as ways of seeing that can help students discover new information they would otherwise miss, thus helping students develop motivation to use their knowledge as well as the experiential value of the new ideas. For example, in teaching geology, an educator framed the lesson as, "every rock is a story waiting to be read," which offers an idea that rocks are not just objects but are interesting narratives that can be interpreted through the lens of geological science ideas (Girod & Wong, 2002). This strategy helped to generate anticipation and experiential value for learning about geology to be able to interpret each rock's "story".

The second teaching strategy is *scaffolding re-seeing.* This teaching strategy is based on Vygotsky's (1978) idea of the *zone of proximal development,* where educators can support students in recognizing opportunities where their knowledge can be usefully applied. This learning theory suggests that although students may not yet be able to independently identify circumstances where they might apply their classroom ideas in everyday experience, an educator can scaffold re-seeing by providing examples or engaging the student with probing questions to help students recognize these opportunities (Pugh, 2020; Pugh et al., 2017). For example, educators can ask for examples of everyday objects or experiences that can be reanalyzed using a scientific viewpoint, coaching students through their attempts to “re-see” everyday phenomena, and/or provide opportunities for students to share their new perspectives with peers. For example, educators could guide students in reinterpreting animal prints through the lens of adaptation and evolution in order to infer the benefits of animals’ patterns and how animal prints might provide camouflage or other benefits to the animal. Scaffolding re-seeing helps students develop and practice expansion of perception, one of the three characteristics of a transformative experience.

The third and final teaching strategy, *modeling transformative experience*s is utilized when an educator models their own thinking regarding a transformative experience. One way to accomplish this is for the educator to share a personal experience of re-seeing the world and obtaining new, valuable perspectives. For example, an instructor might tell a story about their experience going for a hike and knowing where to find a water source due to using a scientific lens to view the surrounding geology and plant life. Through modeling their thought process, educators can help students develop their own cognitive skills of re-seeing as well as inform students about the usefulness of the scientific view, inspiring motivated use and experiential value of the content (Pugh, 2020; Pugh et al., 2017).

Studies implementing these transformative experience teaching strategies in science education show a significant and long-lasting impact on both student learning as well as transfer to students’ daily lives. Students exposed to these teaching strategies show a decrease in scientific misconceptions, increased engagement, expanded perceptions of science ideas in their own lives, higher transfer of science ideas to other courses, and an increased value for scientific knowledge, as measured by surveys, concept tests, and follow-up measures (Girod et al., 2010; Heddy & Sinatra, 2012, 2013; Heddy et al., 2017; Pugh et al., 2009, 2010; Pugh et al., 2017). These strategies were developed in and most often applied to the K-12 setting (e.g., Girod et al., 2010; Pugh et al., 2009, 2010; Pugh et al., 2017). However, studies on transformative experiences in college-level science courses (e.g., Heddy & Sinatra, 2012, 2013; Heddy et al., 2017) have shown promise for the translation of these practices in higher education. And while these teaching strategies have been demonstrated successfully in promoting transformative experiences and helping students transfer their knowledge to their own lives, the body of education literature also suggests that there are particular types of activities that may bolster the effects of these teaching strategies.

One type of activity that has been successful is providing students with *authentic* science experiences in *real-world contexts*. Traditional undergraduate classroom opportunities for students to apply their knowledge typically consist of lectures, papers, exams, and “cookbook” lab explorations (where the result is predetermined). However, these kinds of activities exist only within the culture of formal education and often feel divorced from “real life”. Activities that are *authentic* can help students recognize the ways that science knowledge learned in class can have a real-world impact (Crawford, 2012; Lee & Butler, 2003). Authentic activities in science are those that mirror the real scientific process, where students are able to engage in inquiry, make observations, and use critical thinking and reasoning alongside their science knowledge to solve a real world problem. Often, to add authenticity to in-class learning, lessons simply incorporate examples of real-world data to guide students to think about issues scientists are currently facing, such as oil spills, natural disasters, or climate change. However, to attain an authentic science experience, students also need to be given opportunities to engage in the *inquiry* process of scientific investigation including forming their own questions, performing investigations, and communicating their results (Crawford, 2012; Edelson, 1998; Lee & Butler, 2003). The National Research Council (2000) suggests four essential aspects of scientific inquiry in learning experiences, including:

- Learner gives priority to evidence in responding to questions.
- Learner formulates explanations from evidence.
- Learner connects explanations to scientific knowledge.
- Learner communicates and justifies explanations.

Authentic inquiry activities enable students to develop their knowledge in the context of real-world situations and use methods that mirror real scientific practice (Crawford, 2012; Edelson, 1998; Lee & Butler, 2003). This process helps students relate their classroom knowledge to real-world situations and better understand scientific reasoning and methods. These kinds of experiences may be provided in the classroom, but some learning theories and studies (e.g., Braund & Reiss, 2006) suggest it may be more effective when students are able to undertake authentic activities in environments outside of the classroom.

Situated learning explains that by allowing students to undertake authentic scientific explorations outside of the classroom, they can better bridge the gap between classroom learning and real life. The situated learning theory suggests that knowledge is inseparable from the activities, social settings, and culture from which it is derived and wherein it is used (Brown et al., 1989). This means that "course knowledge" is strongly tied to the classroom environment within which it is created and used, hindering the translation to other environments. For example, the infamous example by Carraher et al. (1985) investigated the math skills of street vendors that they developed and utilized in their daily lives. The vendors performed a wide variety of mathematical functions, including addition, subtraction, multiplication, and division without having the physical products or money in front of them. However, when asked to perform the same mathematical functions in a different environment, given similar mathematical problems represented on paper, the vendors were unable to transfer these abilities. The authors suggested that this inability occurred because the vendor's mathematical cognitive processes are embedded in the circumstances within which they are used (Brown et al., 1989; Carraher et al., 1985). Their knowledge had been shaped by, and was connected to, their daily activities of buying and selling. Having the mathematical problems presented in a different context was a roadblock to accessing and applying that same knowledge. The same can be said of students' classroom science knowledge. They are accustomed to applying science ideas in the contexts of course activities, assignments, reports, and tests, but often don't have the opportunity to access or apply this knowledge in other, real-world settings. Thus, providing authentic science experiences in places students associate with "real life" helps students to be better able to translate their classroom ideas to the real world (Braund & Reiss, 2006).

In science education, there are different kinds of out-of-class activities, from field trips to internships, but one type of activity that may be particularly salient to transformative experiences and authentic science learning is *service learning* or *community-engaged learning.* These types of community-focused learning activities have been defined in many ways, but are commonly described as an experience where students engage in hands-on activities linked to course content to address a need in their community and then reflect on the ways in which these activities are useful and can help address issues in their local environment (Felten & Clayton, 2011; Hou, 2014). For example, ecology students may undertake a plant health survey in an important local nature preserve that provides ecosystem services to the local community, in order to assess the health of the ecosystem and provide recommendations to community managers. This activity is authentic in that the students use methods typical to scientists in the field, engage in inquiry to hypothesize sources of plant damage, and is a service to the community/community-engaged when the students report and reflect upon how the preserve benefits the community, how their results can provide useful information, and think about how to leverage their data to make recommendation to improve the health of their community. Due to the use of reflective exercises as well as the perception of value scaffolded by using science ideas to benefit their local community, this type of learning exercise provides an elegant overlap to the transformative experience education framework (Figure 2).

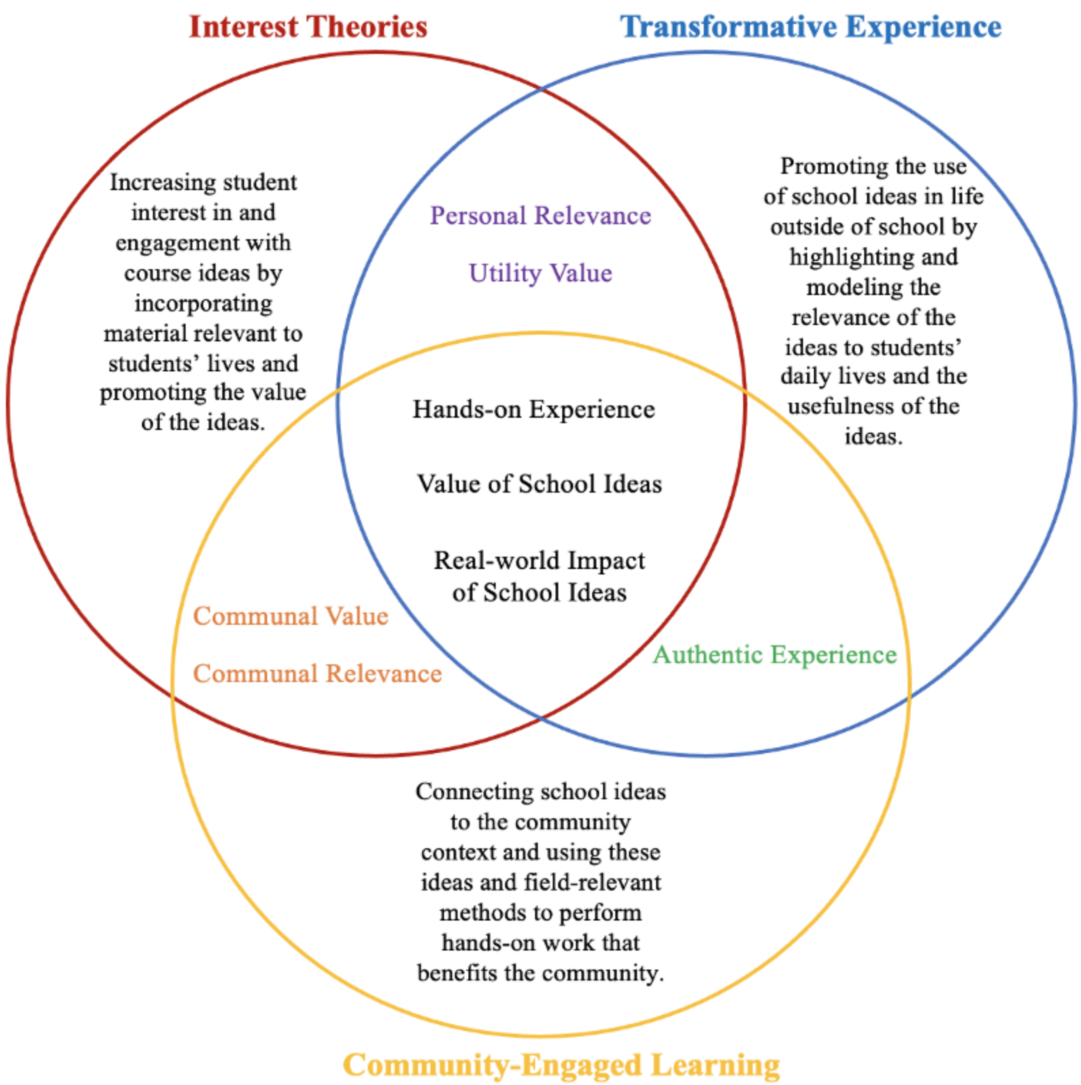

Figure 2. Interconnections Between the Three Major Theoretical Perspectives Utilized

In fact, the foremost author of transformative science education literature has suggested service learning and community engaged learning as particularly relevant contexts for implementing this type of teaching strategy (Pugh, 2020). Even so, there are virtually no studies in the existing literature that have made use of the transformative experience framework in relation to community engaged learning or service learning. A handful of service learning studies have utilized similar *transformative learning* frameworks (e.g., Hullender et al., 2015; Kiely, 2005). However, their instantiations of transformative learning are not the same as transformative experience. These studies focus on transformative learning, which does not place as much emphasis on the engagement that continues beyond the classroom in daily life. And it appears that no studies have combined transformative experience with community-focused experiences in science education, specifically. It appears that service learning and community-engaged experiences are not frequently offered for STEM students, particularly in the life sciences (Woodley et al., 2019). For example, at San Diego State University at the time of this study, there were no service learning or community-engaged learning experiences offered in any STEM fields. As well, these kinds of activities have demonstrated a positive impact on student learning.

Aside from the opportunity to engage in authentic activities and connect with their community, students gain several tangible benefits when they implement service learning. Participating in service learning activities has been shown to enhance student engagement with course content and increase performance, even in large enrollment classes (Markus et al., 1993; Strage, 2000; Warren, 2012; Woodley et al., 2019). Moreover, the hands-on, reflective activities in community settings help students think about the real-world applications of their classroom knowledge (Markus et al., 1993; Strage, 2000). Thus, the combination of service learning and transformative experience has the potential to greatly impact students' abilities to use science knowledge in their daily lives.

The educational frameworks of transformative experience and service/ community-engaged learning can be powerful tools in helping students to recognize the applicability of science ideas to their daily lives. However, simply making students aware of these real-world connections may not be enough for students to successfully transfer their classroom knowledge. Studies in the field of education psychology suggest that student *motivation* is an important factor in determining whether their learning transfers to new settings (Nokes & Belenky, 2011; Pugh & Bergin, 2006). There are many different avenues by which student motivation can be bolstered to enhance the transfer of classroom learning to new environments. These methods include enhancing motivation by incorporating student achievement goals and self-efficacy activities, as well as relating to students' interests (Nokes & Belenky, 2011; Pugh & Bergin, 2006). Due to the nature of transformative experience in highlighting students' personal interests and the social connections provided by community-engaged learning, this study was focused on enhancing student motivation by harnessing student interest through promoting personal and social connections to learning, as discussed in the following section.

Fostering personal and social connections to science content

There are several benefits to helping students perceive their own connections or relevance to the science ideas that they learn in their classes, including increased interest, motivation, and transfer of classroom knowledge to their daily lives (Hartwell & Kaplan, 2018; Hulleman & Harackiewicz, 2009; Nokes & Belenky, 2011; Pugh & Bergin, 2006). Moreover, lack of personal connection to class ideas has been found to be a major factor in students' decision to leave school or change to a different major (Cooper, 2014; Rosenzweig et al., 2021). Thus, to enhance student learning and their ability to utilize classroom knowledge in daily life, it is important to foster personal connections to classroom ideas. The theoretical mechanisms and implications of student connections are explored in the following section.

Interest theory (Hidi & Renninger, 2006) explains that people are more likely and motivated to engage with an activity or task if it is personally interesting. Studies that have explored the interests of students undertaking academic and laboratory tasks have found that persistence, attention, and effort in a task is associated with students' interest in the topic (Hulleman et al., 2017). Therefore, to promote student engagement with ideas, it is beneficial to promote their interest in the subject. Although different students have different specific interests, one general way to promote interest is through connection to student values. The *expectancy-value theory* (Eccles & Wigfield, 2002) explains that people are more interested and likely to engage with tasks or activities if they (a) see value in the task, and (b) expect to succeed in the task or activity. Thus, to promote student interest, curriculum must be scaffolded in ways that students see the science content as valuable and are provided with opportunities to develop positive beliefs about their own science capabilities. This theory is a cornerstone of the transformative experience framework, which seeks to frame classroom ideas as useful, valuable, and accessible to the learner through teaching methods discussed in the prior section (Figure 2; Pugh et al., 2010; Pugh et al., 2017).

From a psychological perspective, there are many ways that a person might come to view an activity as being useful and valuable, but Eccles and Wigfield (2002) recognize four main components that contribute to an individual's perception of value: attainment value, intrinsic value, utility value, and cost. *Attainment value* is the personal importance of completing the task, as it may align with certain aspects of their identity (i.e., a person is perceived as smart, so they have a strong attainment value of a STEM degree because it aligns with how they want to be viewed). *Intrinsic value* is the personal enjoyment of the task by the individual (i.e., a person sees math problems as valuable simply because they enjoy the problem-solving process). *Utility value* is the perception that the task would be useful for a person's current and future goals, even if the individual does not enjoy the task itself (i.e., a person sees working late nights as valuable since it will help them get a promotion). *Cost* is the perceived negative aspects of the task. Utilizing the transformative experience framework to highlight the connections and value of science ideas to students' daily lives can help them perceive the *utility value* or usefulness of these ideas. This not only helps students recognize the applicability of STEM course material in their own lives, but also bolsters their interest and personal connections to course content (Eccles & Wigfield, 2002; Hecht et al., 2021a). *Utility value* is also theoretically the most appropriate value to target in education because it can be connected to external goals, whereas the other three components of value are more internally/personally-driven (Eccles & Wigfield, 2002; Harackiewicz et al., 2016).

Transformative experience teaching strategies rely heavily on influencing students' perception of utility value. In fact, as previously discussed, one of the three characteristics of a transformative experience is *experiential value*, where students are supported in developing greater value for the scientific content by understanding the new, useful perspectives that the science ideas allow them to see and understand (Pugh, 2020; Pugh et al., 2017; Pugh et al., 2010). As well, the transformative experience framework makes a concerted effort to connect to students' experiences and interests to foster their personal connections to science ideas. One of the instructional strategies highlighted in Teaching for Transformative Experiences in Science (Pugh, 2020; Pugh et al., 2017) is *experientially-anchored instruction*, where teachers connect science content to phenomena students' have personally experienced. This can be accomplished by asking students to share relevant examples from their own lives or taking part in a shared activity, both of which help develop personal connections to the science ideas.

In addition to specific teaching strategies that tie into personal connections and provide examples of utility value of science ideas, prior studies have bolstered students' perceptions of student connections and utility value using reflective writing assignments. Hulleman et al. (2017) explain that researchers and practitioners can increase student interest using *value interventions*, writing activities that enable students to recognize the usefulness of the ideas that they are learning about. In these reflective assignments, students are directly or indirectly guided to think about the ways in which the ideas they are learning can have value. Self-generated utility interventions are created when students are instructed to think of ways the task is valuable on their own, rather than directly being told how it is useful; they seem to be the most effective in developing student interest, increasing course engagement, and course performance (Hulleman et al., 2017; Hecht et al., 2021a, Tibbetts et al., 2016). Utility value interventions are found to improve overall student performance but are particularly effective in increasing STEM performance for first generation and students belonging to minoritized groups (Harackiewicz et al., 2016; Tibbets et al., 2016).

The literature suggests that providing opportunities for students to reflect on the value of the science ideas, such as in the utility value interventions, may help overcome one barrier to first generation students, minoritized students, and women's success in STEM (Asher et al., 2023; Brown et al., 2015; Harackiewicz et al., 2014; Harackiewicz et al., 2016). As discussed previously, the culture of the classroom is primarily focused on independent achievement, while the values of first generation students, minoritized students, and women tend to value connection or benefit to community or society (Casad et al., 2018; Cole & Espinoza, 2008; Stephens et al., 2012). By not addressing this in scaffolding of curriculum a barrier of *cultural mismatch* occurs, creating a perception that the values and goals of STEM are not aligned with the social and/or cultural values of these groups. This mismatch negatively impacts their interest and motivation, making persisting in STEM more difficult for these students (Casad et al., 2018; Cole & Espinoza, 2008; Stephens et al., 2012; Brown et al., 2015; Hulleman et al., 2017). The reflective utility value writing assignments help students overcome this barrier by focusing on their personal connections to science ideas, allowing them to think about the ways in which the goals of STEM can be aligned with their personal, social, and/or cultural values (Asher et al., 2023; Brown, et al. 2015; Harackiewicz, et al., 2014; Harackiewicz et al., 2016; Hecht et al., 2021b). Moreover, these effects can be expanded when students are prompted to think not only about their personal connections, but also the connections of the science content to their communities.

Expanding on the self-value focused utility-value reflections, Brown et al. (2015) performed an experimental study with biomedical students using a utility value intervention with both self-value and communal-value treatments. In communal-value interventions students were instructed to think of how the topic of study could help *others*. The authors found that both types of reflection activities increased student motivation, but this effect was enhanced within the "other-oriented" communal utility value treatment group. The focus on communal utility allowed students to recognize the value of their studies for helping others, creating a long-lasting impact on motivation and positive impact on student affect. This finding is particularly significant because STEM is often misperceived by students as being *un*-communal, due to the normative description of science practices as independent and discovery-motivated (Estrada et al., 2018). Thus, these types of *communal* utility value interventions may be particularly useful to promote equity in STEM because women, first generation students, and students belonging to minoritized groups tend to perceive communal goals as more important than individual goals (Boucher et al., 2017; Casad et al., 2018; Cole & Espinoza, 2008; Stephens et al., 2012). Thus, providing opportunities for students to reflect on the communal utility value is one way to increase motivational equity in STEM. However, in addition to reflective activities, there are other aspects of STEM education that can promote students' personal and communal connections to science ideas.

Along with the promotion of student connections to science content, a key component of both transformative experience and authentic science teaching strategies involves inviting students to undertake scientific explorations themselves (Crawford, 2012; Edelson, 1998; Lee & Butler, 2003; Pugh, 2020). When students perform scientific activities, instead of experiencing them second-hand through readings, demonstrations, or videos, they are better able to form personal connections to the ideas, as well as feel more competent in the science practices. Literature shows that when students are able to perform authentic, hands-on scientific practices there can be a positive impact on student interest, self-efficacy, motivation, and connection to STEM ideas (Holstermann et al., 2010; Starr et al., 2020; Trnová & Trna, 2017). This finding aligns with the *expectancy-value theory* (Eccles & Wigfield, 2002), which explains that students are more interested and motivated if they (a) see value in the task, and (b) expect to succeed in the task or activity. By providing students with hands-on activities, they can gain experience with authentic science procedures, allowing them to perceive themselves as capable of undertaking scientific practices, thereby bolstering their expectation that they can be successful in STEM (Starr et al., 2020). It is important to note here that when referring to "hands-on" work, we define this to mean a combination of physical and mental work; it is not enough for students to just to go through the motions, they must also engage with the material in the context of their activity.

(Yannier et al., 2021). The hands-on activities allow educators to tie science content into student experience, through experientially-anchored instruction, which is a key teaching strategy in the transformative experience framework (Pugh et al., 2017; Pugh, 2020).

Similarly to the reflective exercises, the effect of hands-on activities on student engagement and interest may be enhanced when these experiences are connected to their community. Community-engaged learning represents a kind of hands-on experience that ties student hands-on activities to their community (Felten & Clayton, 2011; Hou, 2014). This learning experience represents a crossroads of multiple avenues that promote student connections to science ideas including place-based education and hands-on student learning. By utilizing local environments, educators can tap into place-based education, where students use relevant data and information from nearby places, instead of learning about conventional or arbitrary examples from far-off locations to which students have no immediate connections (Sobel, 2004). An important component of community-engaged and place-based learning is that students are present in the environment that they are learning about and are able to perform hands-on activities in that space (Felten & Clayton, 2011; Hou, 2014; Sobel, 2004).

Place-based learning is centered in the ideas of indigenous knowledge that promotes the interconnectedness of humans and nature, by emphasizing the histories of community contexts and the connections between people and the environment (Johnson, 2012; Johnson et al., 2020; Sobel, 2004). This incorporation of local places in educational experiences helps students create stronger connections to their community and appreciation of the local environment (MacFall, 2012; Warren, 2012). These connections not only help students visualize and appreciate the science ideas they are learning in class, but also help students become more engaged and interested in the environment inside and outside of class. One recent study showed that implementation of place-based practices in higher-education STEM had the ability to increase students' feelings of belonging, persistence, and academic performance (Johnson et al., 2020). While the literature on STEM place-based education remains limited, the findings from community-engaged and service learning studies show that community contexts are a promising venue for fostering communal relevance in classroom learning. These impacts have the potential to help students feel more connected to their community and perceive the social and communal connections that are not typically highlighted in STEM. This not only helps develop personal and communal relevance to science content, but this also helps combat the fact that traditional techniques are not equitable to motivate all students.

In order to help students translate their science learning to their daily lives, this dissertation research project incorporated transformative experience teaching strategies to provide authentic science experiences in community contexts, which were bolstered by reflection activities centered around the communal value of science. By connecting science experiences with community, these methods help to scaffold student use of classroom ideas in the real world as well as help them to make personal and social connections that help motivate them to apply their knowledge. The combination of these frameworks helped to address the following research questions:

1. How can *community-engaged* and *transformative experience* activities be used to foster the recognition and application of science ideas in daily life?
2. How does *community-engaged* experience in STEM impact students' personal and social connections to science ideas?
    A. Do different kinds of students make different connections?

The specific methods employed to answer these research questions are discussed in the following chapter.

Chapter 3 METHODS

This project was a field study including the design and implementation of authentic, community-engaged learning activities, reflective writing prompts incorporated into class assignments, and using transformative experience teaching strategies in a biological science lab class for undergraduate STEM students. This observational study applied a mixed-methods approach to quantitatively analyze student responses to surveys as well as qualitative evaluation of student connections and transformative experiences, performed using analysis of student writing assignments. An observational study allowed for the assessment of the efficacy of community-engaged and transformative experience activities in fostering use of class ideas and the development of connections in college STEM contexts without disrupting the goals of the course curriculum. By measuring students' connections in their writing assignments as well as their self-reported transformative experiences, as they engage with community activities and transformative experience teaching strategies, allows for observation of how combining these treatments can scaffold students' application of science ideas in their own lives and foster personal and communal connections to science content.

Implementation

The project was implemented in two sections of BIOL 354L, a 2-unit, typically 25-person course at SDSU designed to give students hands-on experience with laboratory and field experimentation in Ecology. This course was relevant to the goals of the project as the course is meant as an introduction to authentic research and analysis practices in ecology. This course aims to give STEM undergraduates hands-on, authentic science experiences to bolster their understanding of the science content and methods. Thus, collecting data and learning how to perform and interpret computational analyses in biological research is a main focus. The population of this course is typically 3rd and 4th year undergraduate general biology, ecology, and environmental science students. It is not a mandatory course, but rather an elective lab course loosely tied to BIOL 354, “Ecology and the Environment” which is a prerequisite (or corequisite) course for BIOL 354L, meaning that students typically already have a relatively good understanding of the ecology ideas covered and this class is intended to help students become more immersed in authentic ecological research. The following sections describe the prior existing course and the changes to the course made for this research project.

Existing Course

The specific content and activities of BIOL 354L each semester are largely dependent on the interests of the Ecology PhD students teaching the lab each semester. General course objectives for students include: Gaining exposure to ecological research methods, learning to pose ecological questions, learning to design and implement studies to answer ecological questions, gaining experience reading, analyzing and discussing primary scientific literature, practicing, analyzing and interpreting ecological data, and practicing formal scientific writing. These learning objectives are met through field and laboratory experiments, analysis projects, readings, and written reports on core ecology ideas such as: intertidal ecology, behavioral biology, species interactions, animal migration, intermediate disturbance hypothesis, among others. The main assessment for student grades is typically based on written lab reports and independent projects. No instructional guidance or teaching framework is typically provided to teaching assistants, aside from access to prior course materials. The experimental activities have been performed on campus, online, or in local settings that served only as sources of data, with no real discussion about the context of the data or the connections to students or community.

Course Changes

This study aimed to make very minimal changes to the science *content* typically covered in BIOL 354L; however, the project required changes to the existing course *context* and *teaching methods*, as discussed in the previous chapter. During the field experiences and in written reflections, students were prompted to think about the readings and activities with respect to how the science ideas are relevant to themselves and applied to benefit local communities. Typically, students in this course write summaries of the ecological ideas. This project expanded upon this particular aspect of the course to include reflection upon personal and communal connection to course content.

I assisted with instruction for the two sections of BIOL 354L along with two SDSU Ecology PhD students. My primary role in the two sections was to design and implement the community field activities, while the PhD Teaching Assistants teach the in-class ecology ideas and data analysis methods covered in the course. In the field experiences I used transformative teaching strategies to highlight the relevance of the community locations, field activities, and science ideas to students' daily lives. To help the teaching assistants utilize transformative experience teaching methodologies, I drew from the transformative experience research literature, and specifically the *Teaching for Transformative Experiences in Science* framework to help prepare the teaching assistants to frame and explain the science ideas. Teaching assistants were prepared with selected readings from the science education literature, two 1-hour workshops where we covered the central ideas of transformative experience and student connections as well as planned ecology experiments and community locations. As well, I provided one-on-one teaching support throughout the course. Examples of the types of teaching strategies that were employed are summarized in Table 1.

The community locations were chosen for their relevance to the science content and their availability to accommodate student groups (due to COVID restrictions). In total, students undertook three community field activities: 1) a plant health survey at Mission Trails Regional Park, 2) a tidepool diversity survey at Cabrillo National Monument State Park, and 3) an independent community project of their choosing. Students chose locations such as Torrey Pines State Natural Reserve, Lake Murray Regional Park, Tijuana River Estuary Reserve, La Jolla Cove, among others. In each of the community contexts we drew on methods suggested by transformative experience, place-based education, and community-engaged learning by discussing students' prior experiences in the areas, the importance of each location regarding ecology and community impacts, as well as reviewing the historical and indigenous significance of the location. In each of the locations, students were engaged with authentic scientific methodologies and inquiry.

In each activity they developed their own hypothesis, collected data in the community location using authentic survey practices, used statistical analysis software to interpret their findings, and discussed their findings in a report, linking the data to relevant ecological literature and theories. In their independent community projects, they also developed a research question, hypothesis, methods, and presented the structure and findings of their project to the class. Thus, the course activities met the four essential aspects of authentic scientific inquiry in learning experiences identified by the National Research Council (2000): Using evidence to respond to questions, formulating explanations from evidence, connecting explanations to scientific knowledge, and communicating and justifying their explanations. As well, the readings were chosen to mirror the practices being utilized by the students in the community contents to help students recognize the authenticity of their scholarly efforts.

Table 1. Design principles from the Teaching for Transformative Expereince in Science Framework and related teaching strategies

Design Principle	Purpose	Teaching strategy	Course Example
Frame Content as Explanatory Ideas	Generate idea-based anticipation (how the idea helps students gain new and interesting understandings) and inspire students to use science ideas outside of the classroom.	Framing of scientific content: Use discourse to evoke anticipation and convey the value of the content. Use of compelling metaphors: Use metaphors that evoke anticipation and present the science ideas as compelling possibilities.	Instructors routinely expressed excitement and personal value for the science ideas, processes, and locations. "Performing analyses on data from the natural world allows us to understand and tell stories about why and how the world is the way it is" "Analysis is telling a story"
Scaffold Students' Re-Seeing"	Help students expand their perception and "re-see" the world by viewing it through the lens of scientific content.	Use real-world updates: Introduce and check in on real-world content related to the science idea. Experientially-anchored instruction: Identify and share students' everyday experiences related to the content. Guidance of re-seeing: Provide relevant support to help students reinterpret everyday phenomena, including highlighting connections to science content.	Incorporated examples of similar scientific studies and their impacts. Used real data in examples and practice analyses. Asked students to share their prior experiences in the community locations and tied them into the activities. (e.g., hiking and appreciating nature in Mission Trails, requires that plants are kept healthy by ecological surveys) Used the tidal zones to help students see the physical differences in the zones and relate them to the intermediate disturbance hypothesis.
Model transformative experience	Educator helps transform students' ideas by modeling changes in their own thinking.	Personal explanation of transformative experience: Share personal transformative experiences and express value/passion for the content. Highlight aspects of everyday experience that are changed/enhanced by content knowledge.	"Before I learned about the all the benefits this area provides to the community, I just thought of this place as a pretty place to walk, but now when I see the top of Cowles Mountain, I can't help but think about the ecosystem services this space provides" "Now when I see community parks and green spaces I think about how they help preserve natural species, maintain biodiversity, and help cool the surrounding neighborhoods"

Note. Adapted from Pugh, 2020; Pugh et al., 2017

The transformative experience and service learning literatures both highlight the need for implementing hands-on, experiential learning activities for students that are bolstered by reflective activities (Hatcher et al., 2004; Pugh, 2020; Pugh et al., 2017). The teaching strategies presented in Table 1 are one way to promote student reflection; however, another powerful way to help students reflect on their ideas and connection to daily life is through targeted reflective writing prompts. Existing research, such as that performed by Brown et al. (2015) and Harackiewicz et al. (2016), among others, shows that short, written reflections have the power to harness student motivation in STEM by promoting personal and communal connections to the science content. Thus, the student writing assignments included prompts asking students to review the reading and to make a connection to their own life or to explain the helpfulness of the specific science topic to their community, for example:

> Writing Assignment Prompt:
> Reading summaries should be half page (~250 words) and outline the objective, *brief* methodology, results, and interpretation of results. Introduction: A quick description of the idea covered in the reading. Objective or purpose: What is the purpose and to convey what message? Results: What are the results/conclusions of the study? Interpretation: What is your interpretation of these results? Include 1-2 sentences explaining how this reading is related to an ecology issue facing your community OR an issue related to your personal interests.

These writing assignments served both as a reflective opportunity and as a measure of student progress, as described in the following Evaluation section. There were four independent writing assignments, each with the same prompt. In addition to these independent writing activities that were analyzed to answer the research questions, during each group lab report the students were prompted to discuss their findings with respect to how their data can be interpreted to help the communities surrounding their study location. These offered opportunities for reflection upon both personal and communal connections to the science ideas. Although, these lab reports were group projects, and were not analyzed to answer the research questions, they served as an additional opportunity for student reflection. The methodology for evaluating each research question is presented in the following section.

Participants

Because the course had upper-division biology course prerequisites, all the students (n = 49) who participated in the course were all STEM majors in their 3rd year and above.

Table 2. Participant Demographics

Demographic Category	**Sub-category**	**Number of Students**	**Percent of Students**
Gender Identity	Female	35	71%
	Male	14	29%
College Generation Status	Continuing Generation	37	75%
	First Generation	12	25%
Racial Identity	Hispanic or Latino/a	19	39%
	White or Caucasian	13	27%
	Asian or Pacific Islander	10	20%
	Middle Eastern	5	10%
	Black or African American	1	2%
	Not Reported	1	2%
Highest Degree Sought	Bachelor's Degree	14	38%
	Master's Degree	7	19%
	PhD or Professional Degree	16	43%
Total Students		49	

Evaluation

RQ1: How can *community-engaged* and *transformative experience* activities be used to foster the recognition and application of science ideas in daily life?

This research question was evaluated by surveys and student writing. The anonymous, optional surveys were implemented on the first and last days of the course. The portion of the survey relevant to research question one is the *transformative experience questionnaire*, developed by Pugh (2004). The questionnaire was adapted to the fit the specific context of this study, but has been used in several studies (e.g., Koskey et al., 2018; Heddy & Sinatra, 2013; Pugh et al., 2010; Pugh et al., 2017) to evaluate the degree to which students demonstrate evidence of a *transformative experience*, as defined by Pugh (2002, 2004) to include: motivated use of new information (including continuing motivation), expansion of perception by using new information, and personal experiential value of information to the learner (Table 3). The transformative experience questionnaire has been validated using a combination of quantitative and qualitative measures including the Rasch rating scale and qualitative think-aloud interviews (Koskey et al., 2018). The results showed sufficient coherence (> 40%) between the Rasch model and observed data, and the think-aloud data showed that an average of 76% of the items on the questionnaire achieved cognitive validity, showing agreement between students' answers and the intended measures. As well, the test-retest reliability averaged 0.71 ($p < 0.001$). However, in their validation efforts, Koskey et al. (2018) found that students required clarification of the term "everyday life" because the students often thought of this phrase as referring to "school life". Thus, the survey includes the description of "in my life outside of school" instead of "everyday life" as in the original transformative experience questionnaire.

Table 3. Transformative Experience Questionnaire

Instructions: Think about your BIOL 354L course. For each question, choose the word that best matches the extent to which you agree or disagree.
("Outside of school" refers to your everyday life and experience when you are not in class or working on school assignments. "Ecology ideas" means the ideas covered in BIOL 354L.)

Motivated Use Items	1. I talk about ecology ideas during my class with other students, the TA, or the professor. 2. I talk about ecology ideas outside of school. 3. I talk about ecology ideas just for the fun of it. 4. I think about ecology ideas during my classes. 6. I think about ecology ideas in my life outside of school. 7. I think about ecology ideas when I do things like go to the zoo, visit nature, or see a video about animals, plants, or nature. 8. I find myself thinking about ecology ideas in everyday situations. 9. I use the knowledge I've learned about ecology ideas in class or in my other classes. 10. I use the knowledge I've learned about ecology ideas outside of class. 11. I look for examples of ecology ideas when I watch videos, read books, or experience nature. 12. I seek out opportunities to use my knowledge of ecology ideas in my life outside of school.
Expansion of Perception Items	13. When I learn about other STEM topics during my classes, I see things from the perspective of ecology ideas. 14. When I am working on a class assignment about nature or animals, I can't help but think about the ecology ideas. 15. When I am working on a class assignment about my community/society, I can't help but think about the ecology ideas. 16. If I see a really interesting animal/plant/phenomena/situation in nature (either in real life or on video), I can't help but think about ecology ideas now. 17. I can't help but see parks, beaches, rivers, or estuaries in terms of ecology ideas now. 18. I notice examples of ecology ideas during my other classes. 19. I notice examples of ecology ideas in my life outside of school. 20. I look for examples of ecology ideas in my life outside of school.
Experiential Value Items	21. Ecology ideas are useful for me to learn for my future studies or work. 22. Ecology ideas help me to better understand the world of nature, plants, or animals around me. 23. Knowledge of ecology ideas is useful in my current, everyday life outside of school. 24. I find that ecology ideas make my current, out of school experience more meaningful and interesting. 25. Ecology ideas make nature, plants, or animals more interesting 26. Ecology ideas make STEM classes much more interesting. 27. During my class, I think the stuff we are learning about ecology ideas is interesting. 28. I'm interested when I hear things about ecology ideas in my life outside of school. 29. I find it exciting to think about ecology ideas in my life outside of school. 30. I enjoy explaining ecology ideas that I learn about to my friends. 31. Ecology ideas make me appreciate my local community. 32. Ecology ideas help me recognize the role I have in impacting my community. 33. Ecology ideas help me recognize the role I have in impacting society.

Note. Adapted from Koskey et al., 2019; Pugh 2002; Pugh, 2004; Pugh et al., 2010. Responses are on a 5 pt. Likert scale, Strongly Disagree to Strongly Agree

In addition to the pre- and post-course questionnaire, students' written reflections were analyzed using a transformative experience coding scheme adapted from Pugh and colleagues' study (2010) implementing *Teaching for Transformative Experience in Science* framework in high school biology. This coding scheme measured the degree to which students' written reflections reveal evidence of personal transformative experience while engaging with the science material (Table 4).

Table 4. Transformative Experience Coding Scheme for Reflective Writing Assignments

Transformative Experience Event	**Writing Content Aspects**
Highlighting Experiential Value	Student explains why the science content is useful or relevant to themselves or others. Student expresses anticipation or excitement about a science idea. Student uses a compelling metaphor to explain a science idea.
Practicing Re-seeing	Student provides an example of how science ideas can be applied in everyday life. Student describes the practice of applying science ideas in everyday life. Student identifies an out of school re-seeing opportunity. Student shares an experience of re-seeing.
Modeling Transformative Experience	Student expresses personal value of the science content. Student expresses interest in the science content. Student expresses interest in objects or ideas related to the content (e.g., conservation, restoration, etc.). Student shares a personal transformative experience.

Note. Adapted from Pugh et al., 2010. Coding Scheme is on a 0-2 pt. grading scale. 0 = Aspect not present. 1 = Student provides a weak statement related to the aspect (one sentence added on/superficial/vague). 2 = Student provides a strong statement related to aspect (provides a specific example or justification).

The combination of pre- and post-course survey items combined with qualitative coding of students' written reflections offered data to understand the efficacy of Transformative Experience and service learning in STEM in promoting the recognition, application, and appreciation of science ideas and whether these transfer to students' daily lives. The following sections address the evaluation of the second research question.

RQ2: How does *community-engaged* experience in STEM impact students' personal and social connections to science ideas?

In addition to the pre- and post-course questions relating to aspects of transformative experience, students were also given survey questions related to their personal and social connections to STEM and the degree to which these connections are valued (Table 5). These questions were adapted from surveys published in the literature focusing on student attitudes and personal connections to science (Colorado Learning Attitudes about Science Survey; Adams et al., 2006) and students' social/communal connections to classroom ideas (Measurement of Work Values; Johnson, 2002). Specifically, the *real-word connection* and *personal interest* aspects of the Colorado Learning Attitudes about Science Survey were chosen to evaluate students' personal connections. This survey has been widely used in science education research and has demonstrated efficacy across multiple domains including physics, chemistry, and biology (Adams et al., 2005; Adams et al., 2006; Adams et al., 2008; Perkins et al., 2005; Semsar et al., 2011). As well, relevant questions from the Measurement of Work Values were adapted to measure students' social/communal connections (Johnson, 2002). These types of questions have been previously adapted to measure cultural connections in science education (e.g., Jackson et al., 2016). These questions helped to discover the effectiveness of the treatment in fostering multiple types of student connections to the science ideas.

The *real-word connection* and *personal interest* aspects of the Colorado Learning Attitudes about Science Survey have been validated using interviews and statistical analysis. The interviews showed strong agreement between students' answers and the intended measures on nearly all aspects of the survey (Adams et al., 2005). Statistical analysis has also revealed the strong reliability of this survey (a = 0.845), and factor analysis showed the *real-word connection* and *personal interest* aspects of the original survey were grouped into a single factor, with an internal reliability of a = 0.80 (Douglas et al., 2014).

Table 5. Student Connections Survey Questions

Instructions: Think about your BIOL 354L course. For each question, choose the word that best matches the extent to which you agree or disagree.

Personal Connections	1. I'm excited about Ecology. 2. I like ecology classes. 3. I think the material we study in BIOL 354L is useful. 4. Ecology can be useful in my everyday life. 5. To understand ecology/biology, I sometimes think about my personal experiences and relate them to the topic being studied. 6. Learning about ecology/biology changes my ideas about how the natural world works. 7. The study of Ecology is personally meaningful to me. 8. I have a strong background in Ecology. 9. I believe that I can be successful in Ecology. 10. I'm looking forward to learning more about Ecology. 11. I am interested in careers that use ecology/biology. 12. If I learn a lot about ecology/biology, I will be able to do many different types of careers. 13. The subject of ecology/biology has little relation to what I experience in the real world. 14. To be honest, I just don't find Ecology interesting. 15. Sometimes I'm not sure if I belong in this course.
Social/Communal Connections	1. Ecology can be useful for helping others. 2. Ecology can be useful for helping my community. 3. Ecology can be useful for promoting human health and well-being. 4. I often think about how Ecology applies to human health and well-being. 5. I often think about how Ecology is relevant to societal problems. 6. I often think about how Ecology can be used to improve people's lives. 7. Ecology can be useful for finding solutions to problems people face in their everyday lives. 8. I think the material we study in BIOL 354L is useful for everyone to know.

Note. Responses are on a 5 pt. Likert scale, Strongly Disagree to Strongly Agree

There has been much less exploration and testing of methods to evaluate students' social and communal connections to science ideas learned in class. However, Jackson et al. (2016) have shown the fruitfulness of adapting the Measurement of Work Values to measure social connections to science. Thus, this project will help to further explore how students' social and communal connections to classroom ideas can be measured with surveys.

The survey also included (optional) academic and demographic survey questions to ascertain the potential effects of the treatments on students from different achievement levels and backgrounds (Table 6). These aspects are related to the theoretical frameworks from which the project was designed, as discussed in the previous chapter, including the expectancy-value theory (Eccles & Wigfield, 2002) and the cultural mismatch theory (Cole & Espinoza, 2008; Stephens et al., 2012). The academic information, such as GPA and intended major, is related to students' views of self-efficacy and relevance of the course material to students' academic goals, which may be a factor in influencing their engagement with the course material.

Table 6. Demographic Survey Questions

Information Type	Question
Academic Information	1. Are you enrolled part-time or full-time? 2. What is your current year in college? 3. What is your intended/expected major? 4. What is your current GPA? 5. What is the highest degree you hope to eventually achieve? 6. Based on your performance so far, in general, what grade do you expect to receive in this course? (Post-test only)
Demographic Information	1. What is your age? 2. What most closely represents your gender identity? 3. What is the highest level of education your mother (or guardian) received? 4. What is the highest level of education your father (or guardian) received? 5. What is your mother's (or guardian) occupation? 6. What is your father's (or guardian) occupation? 7. Do you live with your parents or other family members during the academic year? 8. What is your yearly household income? (Provide your best estimate) 9. Do you identify as Hispanic or Latino/Latina? 10. What most closely matches your racial identity?

The demographic information relating to students' gender, ethnicity, and socioeconomic status relate to the differences in the types of connections valued by these groups, which may impact the degree of students' personal and communal contentions to the content. The literature suggests that women, first-generation college students, and students belonging to minoritized groups are more likely to prioritize social or communal connections in science, as compared to male, continuing generation, white students (Casad et al., 2018; Cole & Espinoza, 2008; Stephens et al., 2012).

In addition to the surveys, students' reflective writing assignments were analyzed using a utility-value intervention relevance coding scheme similar to Brown and colleagues (2017) and Harackiewicz and colleagues (2016). Numerical values (0-2) were assigned for multiple qualities of the essays relating to what types of connections and to what degree the students elaborated on this connection, including making associations to oneself, one's community, and society. This way, multiple different types and depths of connections could be evaluated within student writing to ascertain how students' connections changed over the course of their experience with community activities (Table 7).

Table 7. Student Connections Coding Scheme for Reflective Writing Assignments

Connection Type	**Description of Code**
Utility Value	Expresses a topics' usefulness, value, or describes the process of using the idea in order to produce a beneficial outcome
Overall Relevance	Describes how the topic is relevant
Relevance to Self	Describes how the topic is relevant specifically to themselves or their goals
Relevance to Others	Describes how the topics is relevant specifically to another person or a group of people (e.g., scientists, farmers, doctors, etc.)
Relevance to Community	Describes how the topics is relevant specifically to their community or describes a connection to the community field locations
Relevance to Society	Describes how the topics is relevant to society or the world as a whole

Note. Coding Scheme is on a 0-2 pt. grading scale. 0 = Aspect not present. 1 = Student provides a weak statement related to the aspect (one sentence added on/superficial/vague). 2 = Student provides a strong statement related to aspect (provides a specific example or justification).

Student responses were scored based on the highest levels achieved, all essays were coded by a single coder and responses were randomized and blinded during coding to protect the validity of the coding process. The coded essays revealed the types of connections that students are making and how these changed over the course of the class as they continued to experience and reflect upon science activities in community contexts. Further qualitative analysis of essays included thematic analysis to identify substantiating quotes to bolster and illustrate the trends observed in the quantitative data.

To evaluate each research question, specific aspects of each coding scheme were used to measure constructs relevant to the research question (Table 8).

Table 8. Measures Used to Answer Each Research Question

Research Question	**Essay Aspect**	**Coding Scheme**	**Code**
RQ 1	Recognition	Transformative Experience	Practicing Re-seeing
		Student Connections	Overall Relevance
	Application	Transformative Experience	Highlighting Experiential Value Modeling Transformative Experience
		Student Connections	Utility Value
RQ 2	Personal Connections	Student Connections	Relevance to Self
RQ 2, 2A	Social Connections	Student Connections	Relevance to Others Relevance to Community Relevance to Society

Table 9 indicates the sources of data, the number of completed surveys and essays, and the degree to which these sources represent the student participants. The pre survey was administered on the first day of class and the post survey was administered on the last day of class. The average response time was around 15 minutes, survey responses were discarded if they took only a minute or two, resulting in thirty three total surveys used for comparison.

The four writing assignments analyzed for this project were separated in two categories: Pre-Experience Essays and Post-Experience Essays (Table 9) to investigate how student writing changed after being exposed to community-engaged field experiences. Pre-experience essays were tied to readings and activities designed to inform students of methods and analyses in ecology and were not tied to a community-engaged field experience. The post-experience essays were performed after students participated in the field experiences and were connected to readings that mirrored the methodologies they had used in the field. The average scores from the Pre-Experience and Post-Experience essays were compared to answer the research questions. The analyses and their results are described in the following section.

Table 9. Data Sources for the Analyses

<table>
<tr><th colspan="3">Data Source</th><th>Response Rate</th><th>Number Completed</th><th>Number Matched + Analyzed</th><th>Percent of Students represented</th></tr>
<tr><td rowspan="2">Surveys</td><td colspan="2">Pre-Survey</td><td>98%</td><td>48</td><td rowspan="2">33</td><td rowspan="2">67%</td></tr>
<tr><td colspan="2">Post-Survey</td><td>80%</td><td>39</td></tr>
<tr><td rowspan="4">Essays</td><td rowspan="2">Pre-Experience Essays</td><td>Essay 1</td><td>94%</td><td>46</td><td rowspan="4">45</td><td rowspan="4">94%</td></tr>
<tr><td>Essay 2</td><td>94%</td><td>46</td></tr>
<tr><td rowspan="2">Post-Experience Essays</td><td>Essay 3</td><td>92%</td><td>45</td></tr>
<tr><td>Essay 4</td><td>94%</td><td>46</td></tr>
</table>

Note. Total n = 49.

Confidentiality

In compliance with IRB standards (SDSU Human Subjects IRB Protocol#: HS-2021-0176), students were notified that their participation with the surveys was entirely voluntary and fully anonymous. Students were informed that the surveys would not affect their grades and would never been seen by the teaching assistants. Students were incentivized to participate by the teaching assistants offering a small percentage of students' participation points. Students who did not wish to participate could earn these points instead by partaking in the normal participation exercises in class (asking or answering class questions). All students volunteered to anonymously partake in the survey and to have their writing assignments anonymously analyzed. Students were provided with consent forms that informed them of their privacy and confidentiality.

Positionality Statement

Makenna Martin is a Caucasian, cis-identifying woman, who has studied in STEM fields for her bachelor's and master's degrees. She has been fortunate to have been provided with many formative, hands-on learning experiences throughout her K-12 and college career, which have strengthened her passion for science education and outreach. Makenna has been a research assistant for various educational research projects at San Diego State University, a large, Hispanic-serving, research university in Southern California. Makenna has experience teaching across a variety of age ranges, from K-12 science camps to undergraduate lab courses. Makenna would like to recognize the graduate teaching assistants for all their time and effort in this project.

Chapter 4 RESULTS

The data sources for this project included pre- and post-course surveys and pre- and post-field experience student writing assignments. Quantitative analyses were performed comparing students pre- and post-course surveys. As well, qualitative coding was performed on student writing using two coding schemes: the *Transformative Experience* scale and the *Social and Personal Connections* coding scheme. The specific aspects of the surveys and essay codes related to each research question are described in the previous section. The applied codes were quantitatively analyzed. Student writing was also qualitatively analyzed using thematic analysis to report relevant examples. The results of the analyses are reported in the following section, organized by research question.

RQ1: How can *community-engaged* and *transformative experience* activities be used to foster the recognition and application of science ideas in daily life?

The results for research question one are presented below and organized by data source.

Surveys

The data indicated that students were better able to both recognize and apply science ideas to their daily lives after their experiences in the course. Comparing pre- and post-course surveys revealed an increase in scores related to student recognition and application of science ideas (Table 10). Paired-samples t-tests confirmed these increases are statistically significant, indicating growth in students' self-reported ability to recognize and apply science ideas within class, in their daily life, and overall.

Table 10. Results of the Survey: Recognition and Application Scores

Category	Sub-category	**Pre-Course**	**Post-Course**	**t**	**p**
Recognition of Science Ideas	Recognition in Classroom	3.68	4.01	– 3.798	< 0.001***
	Recognition in Daily Life	3.67	3.92	– 2.507	0.009**
	Overall Recognition	3.67	3.97	– 4.079	< 0.001***
Application of Science Ideas	Application in Classroom	3.97	4.20	– 1.960	0.029*
	Application in Daily Life	3.91	4.06	– 1.702	0.049*
	Overall Application	3.92	4.09	– 1.882	0.034*

Note. Responses are on a 5 pt. Likert scale, Strongly Disagree to Strongly Agree. (n = 45)

Essays

Student essays similarly revealed an increase in students' ability to recognize science ideas after their experiences in the course. This was evidenced by the significant increase in the number of codes applied to student writing related to recognition in the post-field experience essays (Table 11). However, the essay results for students' ability to *apply* science ideas were mixed. Student essays showed an increase in one aspect of application; however, the other aspect of application was not significantly changed.

Two linear regressions were run to investigate if students' recognition and application essay scores could predict their post-course survey scores for recognition and application, respectively. To control for students' pre-test scores, centered pre-course survey scores were used as a covariate. When predicting post-course recognition scores, the overall model was statistically significant ($F(3, 29) = 17.414$, $p < 0.001$, $R^2 = 0.606$), but that survey scores alone were not significantly predicted by the individual essay scores related to recognition.

Table 11. Results of the Reflective Writing Assignments: Recognition and Application Scores

Category	Coding Scheme	# of codes	Scale	Pre Experience	Post Experience	t	p
Recognition of Science Ideas	Transformative Experience	1	0 - 2	0.12	0.28	– 2.461	0.009**
	Student Connections	1	0 - 2	0.41	0.54	– 2.019	0.025*
Application of Science Ideas	Transformative Experience	2	0 - 2	0.49	0.77	– 2.891	0.003**
	Student Connections	1	0 - 2	0.8	0.93	– 1.337	0.094

Note. n = 33

The recognition essay codes related to personal and social connections (β = – 0.096, SE = 0.157, t(3, 29) = – 0.0674, p = 0.506) and transformative experience (β = 0.238, SE = 0.170, t(3, 29) = 1.683, p = 0.103) did not significantly predict students' self-reported ability to recognize science ideas. Similarly, when predicting post-course application scores, the overall model was statistically significant (F(3, 29) = 7.669, p < 0.001, R^2 = 0.384), but that survey scores alone were not significantly predicted by the individual essay scores related to application. The application essay codes related to personal and social connections (β = 0.090, SE = 0.281, t(3, 29) = 0.229, p = 0.821) and transformative experience (β = 0.135, SE = 0.314, t(3, 29) = 0.345, p = 0.733) did not significantly predict students' self-reported ability to apply science ideas. In addition to the quantitative analyses described above, student writing also provided supporting qualitative evidence for research question one, discussed in the next section.

Qualitative Data

As previously discussed, the quantitative analyses of the essay coding showed that students' scores significantly increased for both essay aspects of recognition, and one of two aspects for application. Reviewing the post-field trip student essays using qualitative thematic analysis bolstered these results by demonstrating the complexity of student thinking surrounding the recognition and application of science ideas in their daily lives (Braun & Clarke, 2006; Table 11).

Overall, the results for research question one were compelling. Quantitative analyses revealed that the surveys show a unilateral increase in students' self-reported ability to recognize and apply science ideas both in their courses and in their daily lives. This increase was also seen in student writing, where quantitative analysis of qualitatively-coded essays showed increased recognition scores across both coded aspects and increased scores for one out of two aspects of application. The regression analyses showed that the essays may have impacted students' survey scores, with students' essay scores able to significantly predict students' post-course survey scores related to both recognition and application. Qualitative thematic analysis of student writing bolstered evidence for this idea, revealing the depth of student thinking surrounding recognition and application of science ideas learned in their class.

Table 12. Student Quotes Supporting the Recognition and Application of Science Ideas

Theme	Supporting Quote
Recognition of Science Ideas	I believe that the data gathered in [the paper] demonstrated the relationship between environmental stress and species diversity, as similar patterns were also seen at Cabrillo tide pools. While gathering data from the tide pools, it was apparent that intermediate tide areas had the greatest abundance of species, as well as a large array of different species. It was great to witness the relationship first hand and why the research done by [the paper] is relevant to ecosystems around us and how we can conduct similar research in the field.
	This article made me think about the types of processes going on around me, and the relationship the processes form with herbivory, especially with what we saw in Mission Trails.
	It is so cool how something like the tide is able to cause environmental stressors on specific tide zones changing species abundance. This makes me wonder how the abundance in different areas affects species which feed on certain species in the different tide areas. It was cool being able to see the environmental stress model in action when looking at the tidepools at Cabrillo National Monument.
	All in all, I found this experiment to be something cool to think about mainly because I didn't expect the species to be most populated at mid-level as opposed to the extremes. I thought that as the water level was lower, the species richness and diversity would increase because there was more access to the ocean, which is so diverse in the kinds of organisms that live there. What makes this study important to me though, is that the preservation of habitats like intertidal pools because changes in the environment can displace and even drive species to extinction over time.
Application of Science Ideas	I loved the idea of exploring the intertidal zones for more information about environmental stressors. I believe that it is important to get information like this for our benefit as well as for the animals. In other words, we would be helping the animals by conserving and protecting the areas, while they will help us better understand not only their life cycles but also oceanic changes (e.g., temperature change, salinity, etc.). This is important for us to know as it affects us as much as it would the marine animals (e.g., resources). Overall, comprehending any animal's abundance and diversity, and its stressors, can help for conservation and restoration of their habitat.
	This study is very relevant especially for this course and the similar experiment we just conducted at the Cabrillo tide pools. Since confirming the predictions made by [the Environmental Stress Model], we can hopefully start to use this model on other taxonomic groups to predict species diversity with differences in stress. The more studies done to increase understanding of the effects of stress on diversity, the more we might be able to understand ecosystem dynamics and construct effective conservation projects.
	... We need to try and understand the mechanisms and interactions playing out between animals and plants if we want to protect it. [...] I believe that this is a relevant contribution as it helps us to see just how important interactions are between species. This relates to what we learn in the majority of our biology courses because we need to understand the ecological changes in the environment if we are thinking about introducing a new plant or animal species.
	I had no idea that species richness could be measured on a unimodal trend based on vertical elevation. This really showed me that almost anything can be quantified and put into some form of data in order for it to be even more understood.

RQ2: How does *community-engaged* experience in STEM impact students' personal and social connections to science ideas?

The results for research question two are presented below and are organized by data source.

Surveys

The survey data showed no effect of the community-engaged experiences on students' self-reported ability to create personal and social connections to science ideas. Comparing pre- and post-course survey data showed a slight improvement of personal and social connection scores, but this change was not a significant difference (Table 13).

Table 13. Results of the Survey: Student Connection Scores

Category	**Scale**	**Pre Course**	**Post Course**	**t**	**p**
Personal Connections	1 - 5	4.09	4.17	– 0.708	0.242
Social Connections	1 - 5	4.27	4.31	– 0.298	0.384

Essays

Comparing student essays before and after their field experiences showed that after the community-engaged experiences, the students were better able to establish personal connections to the scientific content in their writing. Using the student connections coding scheme, paired-sample t-tests confirmed a significant increase in the number of personal connections in student writing (Table 14). However, there was no significant change in the number of *social* connections students made after their field experiences.

Table 14. Results of the Reflective Writing Assignments: Student Connection Scores

Category	**Scale**	**# of Codes**	**Pre-Experience**	**Post-Experience**	**t**	**p**
Personal Connections	0 - 2	1	0.68	0.95	– 2.918	0.003**
Social Connections	0 - 2	3	0.23	0.27	– 0.691	0.247

Two linear regressions were run to investigate if students' personal connection scores and social essay scores could predict their post-course survey scores for personal and social connection. To control for students' pre-test scores, students' centered pre-course survey scores were used as a covariate. The regressions revealed that personal (β = 0.138, SE = 0.117, p = 0.365) and social (β = 0.281, SE = 0.161, p = 0.108) connection essay scores did not significantly predict students' reported post-course connections to science ideas. In addition to the quantitative analyses described above, student writing also provided supporting qualitative evidence for research question two.

Qualitative Data

As previously discussed, quantitative results showed that students made significantly more personal connections in their writing after their community-engaged learning experiences. This was also apparent in the substance of their essays; reviewing the two essays students performed after their field experiences using thematic analysis showed many students made a variety of connections between the scientific content to their own lives (Braun & Clarke, 2006; Table 14). Although the quantitative results for students' social connections did not reveal a significant change, the qualitative evidence presented here serves to illustrate the thinking of the students in the course who made connections to others, their community, or their society (See Tables 13 and 14).

Table 15. Student Quotes Supporting Student Connections to Science Ideas

Theme	Supporting Quote
Personal Connections to Science Ideas	This [ecosystem] is important to me as a researcher because it provides a hyper-sensitive environment to determine the effects of environmental changes. If, for example, the temperature of the earth changes by just a small amount, then an intertidal ecosystem can be devastated while surrounding ecosystems may remain unphased. These results are also important to me as a researcher because it keeps me more informed in terms of how intertidal ecosystems function and how this is similar and different to other potential ecosystems
	This is significant to me because I plan on doing research on ecology in the future. Studies like these serve as an important reminder to not make any assumptions when it comes to ecology.
	... if humanity continues to research the fragility and dynamics of ecosystems and how they have functioned, function presently, and will function in the future, there is hope for many of the endangered systems around the world. The research was fascinating as I have always been connected to nature and the fragility within the world's ecosystems. The paper also paved the way for my future understanding of disruptions within ecosystems and the organisms that inhabit them.
	This paper is applicable to me and others studying ecology, because it provides ideas on how to improve studies that already exist and how to apply these results to other taxa, like terrestrial animals. Because I study rattlesnakes, a terrestrial species, it would be interesting to see how these studies and ideas would apply to them.
Social Connections to Science Ideas	When we are able to add onto our knowledge about how species distribution works, it can only lead to more advances in the ecology field. This relates to what we learn in our science classes and within our community because a better understanding of this topic is beneficial in developing conservation and restoration plans if needed.
	I think it is important that more research is done on invasive species and how they affect native species for both plants and animals. Many people introduce new species whether it be for their backyard or pets, and it can cause an imbalance or hurt the local ecosystem.
	This paper is related to my community and the rest of the world because there is a section in it about climate change and how human behavior can affect and harm wildlife and their movement behavior. Following the industrial revolution, humans have been irresponsible and unsustainable— and the repercussions are now showing in our beloved ecosystems.
	I believe that this research provides a better understanding of what factors should be considered and how to evaluate top-down and bottom-up forces in order to find out ecosystem and species interactions. If we know how to study ecosystems and have a proper knowledge, we can solve a lot of ecological issues that our community faces on a daily basis.

RQ2A: Do different kinds of students make different connections?

According to the literature, particular groups of students in STEM, including women, first generation students, and underrepresented minoritized groups (URM), are more likely to make social connections than their peers who do not belong to these groups (e.g., Asher et al., 2023; Boucher et al., 2017; Brown et al., 2015; Harackiewicz et al., 2014; Harackiewicz et al., 2016; Hecht et al., 2021). To test whether different types of students made different kinds of connections, multiple linear regressions and ANOVAs were run to investigate whether membership in these groups could significantly predict post-course survey scores and post-field experience essay scores related to social connections. For each model, the relevant post-test scores were regressed onto a model that included the matched, centered pre-test variable and code variable for group membership. Only a single demographic group was included in each model, as this study was not adequately powered to test for intersectionality of multiple groups. Gender was coded as: 0 = men, 1 = women, and college generation status was coded as: 0 = continuing generation, 1 = first generation. Ethnicity required an ANOVA to analyze the three groups being compared (1 = URM students, 2 = Asian students, and 3 = White students). The results of these models are reported below.

First, relating to women in STEM, regression analysis showed that gender did not significantly predict post-course social connection survey scores (β = – 0.107, SE = 0.211, p = 0.532) or post-field experience essay scores (β = 0.39, SE = 0.133, p = 0.785) related to social connections. Second, relating to first generation college students, regression analysis showed that generation status did not significantly predict students' post-course social connection survey score (β = 0.31, SE = 0.192, p = 0.063) or post-field experience essay score (β = – 0.173, SE = 0.138, p = 0.222). Third, relating to URM students, two ANOVAs were performed, one for social connection survey scores and one for social connection essay scores. The survey ANOVA revealed that there was no significant difference in the social connection scores of students who identified as different ethnicities $F(3, 34) = 2.416$, $p = 0.086$. However, the essay ANOVA showed there *was* a significant difference in the post-field experience scores between the different student groups $F(2, 44) = 4.949$, $p = 0.012$. Pairwise analysis showed Asian students ($M = 0.750$, $SD = 0.382$) scored significantly higher in their post-field experience social connection scores compared to both URM students ($M = 0.316$, $SD = 0.304$; $p = 0.003$) and White students ($M = 0.425$, $SD = 0.508$; $p = 0.029$), while URM students in the course did not score significantly differently than White students ($p = 0.391$).

Lastly, although the initial goal was to further analyze intersectional groups of students to see if belonging to multiple groups was related to students' ability to make social connections, the sample size of the current study did not allow for this level of analysis. Explanations and implications of the analyses reported in this section are discussed in the following chapter.

Chapter 5 DISCUSSION

The goal of this study was to combine Transformative Experience teaching strategies and community-engaged field experiences to foster students' recognition and application of science ideas in their daily lives, as well as to promote personal and social connections to the course content. Using quantitative analysis of student surveys and essays before and after their course experiences, alongside qualitative evidence from student writing, provided evidence to answer the research questions of this study. A discussion of the results are presented in the following sections. First, the results and evidence used to answer each research question are discussed. Second, the general discussion section explores connections to existing literature, implications for future research, and the limitations of the study.

Summary and Interpretation of Results

The first guiding question of this study was to investigate how community-engaged and Transformative Experience activities can be used to foster students' recognition and application of science ideas in daily life. This study provided strong evidence that these methodologies can be used together successfully to help students recognize and apply the ideas from the course content in their own lives. This was substantiated by comparing students' pre- and post-experience surveys and writing assignments. By measuring students' own perception of their recognition and application capabilities in surveys, as well as evidence of their ability to demonstrate these skills in writing, these data provide robust documentation to answer research question one. Quantitative analyses indicated that students' ability to recognize and apply science ideas was enhanced after their experience in the course (Table 11). Students were better able to connect the ideas they learned in the course both to other educational contexts (e.g., in other classes) and to their lives outside of classes. The results revealed that after the course, students perceived, implemented, and valued the insights that the science ideas contributed to their life outside of class.

In addition to the quantitative evidence, student writing before and after the field experiences were compared to provide qualitative evidence supporting research question one. The qualitative evidence from student writing served to both validate and bolster the quantitative findings from the surveys and the essays regarding students' increased ability to recognize science ideas in their daily lives. Quantitative analysis of student writing revealed that the essay scores significantly increased across both measures for students' recognition of science ideas (Table 12). This trend was also observed qualitatively in student writing. Thematic analysis of students' statements from post-field experience essays demonstrated their recognition of science ideas as valuable both within class and in their daily lives. For example, one student wrote:

> I believe that the data gathered in [the paper] demonstrated the relationship between environmental stress and species diversity, as similar patterns were also seen at Cabrillo tide pools. While gathering data from the tide pools, it was apparent that intermediate tide areas had the greatest abundance of species, as well as a large array of different species. It was great to witness the relationship first-hand and why the research done by [the paper] is relevant to ecosystems around us. (Post-field experience essay 2; See Table 12 for more supporting quotes)

In their writing, this student revealed that during their field experience they recognized the value of the science idea of the *intermediate-disturbance hypothesis*, which was an idea discussed in class and in a reading assignment linked to this experience (Ali & Kumar, 2020). The intermediate-disturbance hypothesis is the idea that the areas with intermediate or medium amounts of environmental stress or disturbance (as compared to areas of low- and high-stress) will demonstrate greater abundance and diversity of plants and animals (Ali & Kumar, 2020; Fox & Connell, 1979). In the above excerpt, the student explained how they observed the science idea first-hand while performing data collection, and how they recognized how this idea was relevant not only to the local tide pool setting but to other ecosystems. The student's writing revealed the connections they made between the class idea, their hands-on experience, and the possibility of this pattern occurring in other ecosystems in the real world. Thus, the writing provided evidence that this student is *modeling* a *transformative experience* (Pugh et al., 2010).

As discussed in the background section, *modeling a transformative experience* is one of three aspects used to measure the degree to which students have undergone a Transformative Experience (Table 3). Transformative Experience is relevant to research question one because this construct is designed to evaluate whether students have achieved the ability to transfer classroom knowledge to enhance their daily lives (Pugh, 2011, 2020; Pugh et al., 2009, 2010). Students can model this particular aspect of Transformative Experience in their writing by describing relevance, personal interest, and/or describing how the experience has changed their perspective (Table 3; Pugh et al., 2010). Modeling a Transformative Experience in this way is related to recognition because these kinds of descriptions require students to notice how a classroom idea is related to themselves, their interests, or their environment. Overall, student writing showed strong support that community-engaged and Transformative Experience activities can effectively foster the *recognition* of science ideas in students' daily life.

The findings indicate that students' *application* of science ideas was similarly enhanced, though not to the extent of recognition. Related to the application of science ideas, student writing showed a significant increase in only one of the two essay measures for application (Table 11). Although the second measure of application was increased in the post-field experience essays, it was not enough to indicate a significant change. This trend was also observed qualitatively in student writing. Thematic analysis of students' statements from post-field experience essays illustrated student thinking surrounding their application of science ideas both within class and in their daily lives. For example, one student wrote:

> I loved the idea of exploring the intertidal zones for more information about environmental stressors. I believe that it is important to get information like this for our benefit as well as for the animals. In other words, we would be helping the animals by conserving and protecting the areas, while they will help us better understand not only their life cycles but also oceanic changes (e.g., temperature change, salinity, etc.). This is important for us to know as it affects us as much as it would the marine animals (e.g., resources). Overall, comprehending any animal's abundance and diversity, and its stressors, can help for conservation and restoration of their habitat.
> (Post-field experience essay 2; See Table 12 for more supporting quotes)

In their writing, this student described the application of the science idea of the *intermediate-disturbance hypothesis*, which was discussed in the class and reading assignment linked to this experience (Ali & Kumar, 2020). The student provided an eloquent description of how the idea is applied and how the application of the idea is valuable to both humans and the ecosystem being studied. They explained how this science idea was applied to allow for understanding of how real-world environmental stress can affect animals. The application of this scientific idea was valuable because it led to increased success in implementing conservation or restoration plans for animals, as well as allowed humans to understand environmental changes and the impacts on the natural resources we rely upon. This connection between the science idea, its use in the real-world, and the value of the idea for providing helpful information and outcomes demonstrated that this student is *practicing re-seeing* and *highlighting experiential value,* two aspects of Transformative Experience that relate to students' ability and motivation to apply science ideas in their daily lives (Pugh et al., 2010). Students demonstrate practicing re-seeing in their writing by identifying, explaining, or describing the practice of applying classroom ideas in daily life (Table 3). Students demonstrate highlighting experiential value by explaining why a classroom idea was exciting, useful, or valuable to themselves or others. These aspects of Transformative Experience are related to application because they require students to think about and describe the real-world implementation and outcomes of the science ideas they are learning in class. Overall, student writing offered some support that community-engaged and Transformative Experience activities were effective in helping students apply science ideas in their daily lives, even if not all the essay aspects were significantly increased.

A few factors could have contributed to the fact that recognition was significantly increased unanimously across essay scores, but application showed only one significant increase: a) the differential difficulty in recognition versus application, b) the design of the prompts, and c) a potential ceiling effect. Indeed, promoting student application of ideas can be more difficult to achieve than recognition alone, as research has shown that students often fail to apply relevant knowledge to new scenarios unless motivated to do so through the activity structure, personal interest, or other influences (Pugh & Bergin, 2006). It also may be the case that specific essay prompts used in this study were better able to promote recognition than application. Additionally, there is evidence of a ceiling effect; the one essay aspect that was not significantly changed had the highest pre-score, so it had less room to change (Table 11). In fact, the unchanged essay aspect started at a higher (pre) score than all the other scores ended (post), meaning the intervention probably did not have the opportunity to influence this aspect because it appears to already be well-developed within this particular group of students.

Further analysis evaluated if students' essay scores could significantly predict their post-course survey scores related to recognition and application of science ideas. However, the results showed that essay scores were not able to predict the higher post-course recognition and application scores seen in the surveys. This finding could indicate that other aspects of the class, such as the course content, teaching methods, field experiences, or some combination of these (or other) factors, were important in influencing the higher recognition and application scores. Another potential explanation could be that the essay coding measures used in this study were less precise than the survey measures. It is possible that even if students did experience an increase in their abilities to recognize and apply science ideas, they just didn't demonstrate their abilities well in their essays. As described in the methods section, the essays were short writing experiences, and perhaps more prolonged or frequent opportunities for writing would help students demonstrate their abilities. Suggestions to address these issues for future implementation are explored in the general discussion section of this chapter.

To summarize findings for research question one, the quantitative data unilaterally provided compelling evidence that community-engaged and Transformative Experience activities can effectively foster the *recognition* of science ideas in students' daily lives. This conclusion was evidenced by higher survey and essay scores. The data also showed strong evidence that these experiences are helpful for promoting the *application* of science ideas in students' daily lives, through higher survey scores and an increase in one of the two essay scores for application. Qualitative analysis of student writing provided both validation of these quantitative results as well as served to illustrate examples of student thinking regarding the recognition and application of science ideas in their daily lives.

The second guiding question for this study was to investigate how community-engaged experiences in STEM impacts students' personal and social connections to science ideas. This study found that these experiences did not significantly change students' perceptions of their connections to science ideas. Although, interestingly, student writing showed an increase in students' ability to make personal connections to the scientific content. The pre- and post-experience surveys and writing assignments provided evidence for research question two. The quantitative analyses showed that, although the students' scores were slightly higher in the post-experience surveys, there was not a significant difference in students' self-reported personal and social connections to science ideas (Table 14). However, the students in the course demonstrated extremely high scores in their pre-test, already averaging 4.1 and 4.3 (out of 5) for their social and personal connection survey scores, respectively, prior to their class experience. So, it is possible that there was limited room for improvement in these particular aspects, as they appeared to already be well-developed in this particular group of students.

Comparing students writing before and after their community-engaged experiences revealed that there was a significant increase in students' personal connections (Table 14). Students' social connections were also slightly higher after their field experiences; however, not enough to reach the level of significance. Further analysis showed students' essay scores did not significantly predict their post-course survey scores related to personal and social connections. Overall, the quantitative data revealed that there is some evidence for community-engaged field experiences helping students to make more personal connections to science ideas in their writing; however, this trend was not observed in students' social connections.

Thematic analysis of qualitative data in the form of student essays provides validation, bolstering evidence, and descriptive illustrations for the personal and social connections students made during the course. Quantitative analysis showed that students made more personal connections to science ideas over time, and this trend was also observed in the qualitative data, one student wrote:

> This [ecosystem] is important to me as a researcher because it provides a hyper-sensitive environment to determine the effects of environmental changes. If, for example, the temperature of the earth changes by just a small amount, then an intertidal ecosystem can be devastated while surrounding ecosystems may remain unphased. These results are also important to me as a researcher because it keeps me more informed in terms of how intertidal ecosystems function and how this is

> similar and different to other potential ecosystems. (Post-field experience essay 2; See Table 15 for more supporting quotes)

The student described themselves on multiple occasions as a "researcher" and explained the personal significance of not only the location, but also the science idea and related results. The student explained how, as a researcher, they can use this sensitive environment as a barometer and predictor for environmental damage. As well, they explained how the results provided them with useful information for going forward in their classes or their research.

While these types of connections may seem more related to the field of ecology rather than the students' personal life, this students' writing consistently revealed they identified themselves as an ecology researcher, even writing in another essay that they plan to conduct ecology research as a career path. Thus, the ideas in this example illustrated a personal connection directly related to their personal life and professional goals. This was a common theme among student responses in this course, with many other students making personal connections to their current experiences or future careers as researchers, with another student describing that one science idea covered in class was, "significant to me because I plan on doing research on ecology in the future. Studies like these serve as an important reminder to not make any assumptions when it comes to ecology" (Post-field experience essay 1; See Table 15 for more supporting quotes and essay prompt). In fact, all the students in the class were STEM majors, with 62% reporting that they intended to seek higher education (Master's, PhD, or Professional Degree; Table 2). So, there is evidence that many of the students may have been able to connect to these kinds of personal educational or professional goals.

While the quantitative results did not show a significant difference in the number of social connections students made in their writing, the thematic analysis of qualitative data of student essays served to provide an illustration of some of the social connections students made in the course. In their writing, many students connected the science ideas in the course to issues in their communities, for example: people releasing their invasive species pets into their neighborhoods, the development of conservation and restoration plans for local ecological issues, and even the implications for society, with one student reflecting that, “human behavior can affect and harm wildlife (…) Following the industrial revolution, humans have been irresponsible and unsustainable — and the repercussions are now showing in our beloved ecosystems” (See Table 15 for more supporting quotes and essay prompt).

To summarize findings for research question two, the quantitative data showed mixed evidence for the ability of community-engaged experiences to develop students’ personal connections to science ideas. While the survey showed no significant change, student writing demonstrated that students made significantly more connections to their own lives after their community-engaged experiences. Regarding social connections, quantitative analysis of the surveys and essays showed no significant change in students’ social connections to science ideas. Qualitative analysis of student writing served to validate the quantitative findings about students’ personal connections to science ideas as well as illustrate examples of student thinking regarding both personal and social connections.

The last guiding question is related to research question two; specifically looking into whether different groups of students made different types of connections in their writing. Although prior research provides strong evidence that women, first-generation students, and students belonging to minoritized groups are more likely to engage with community connections in education and thus make more social connections in their writing (e.g., Casad et al., 2018; Cole & Espinoza, 2008; Stephens et al., 2012), this study did not replicate these findings. Providing opportunities for students to reflect on the social relevance and value of the ideas they are learning has been shown to be particularly impactful for minoritized student groups and have allowed them to make more social connections compared to students in majority groups (White, male, continuing-generation students; Asher et al., 2023; Boucher et al., 2017; Brown et al., 2015; Hecht et al., 2021). To evaluate if this pattern was observed in the data from this study, analysis was performed on the social connection aspects of the surveys and essays to compare the number of social connections made by women, first-generation students, and students belonging to minoritized groups.

Comparing the social connection scores of both the surveys and the essays showed that this study did not replicate the prior findings that first-generation students, women students, and students belonging to minoritized groups tend to make more social connections than their majority counterparts. Analysis revealed that there were no significant differences between first-generation students compared to continuing-generation students, between men compared to women, and between the students belonging to minoritized groups and white students in the course, thereby answering the last guiding question. Possible factors that may have impacted this lack of replication are discussed in the following general discussion section.

General Discussion

Upon analyzing student surveys and writing to answer this study's research questions, three trends emerged that are relevant to the fields of teaching and education research. First, this study shows that the Transformative Experience and community-engaged frameworks can be effectively combined. Furthermore, this combination appears to be especially fruitful in enhancing student recognition and application of their scientific knowledge to new contexts, including in their daily lives. Second, the field experiences implemented in the course were effective in promoting students' views of self-efficacy, which is important for enhancing student success in STEM. And third, although the methods used promoted students' personal connections in their writing, to facilitate more robust personal and social connections, it is essential to provide additional opportunities for reflection. These three themes, and their relevance to the literature, are discussed in the following sections.

Transformative experience and community-engaged learning combined enhances student recognition and application of science ideas.

Transformative experience strategies scaffold students' personal connections to the science content; helping students to recognize the science in their daily lives, which can help overcome emotional and motivational barriers to learning (Heddy & Sinatra, 2013; Pugh, 2020; Pugh et al., 2017). Prior studies using a Transformative Experience framework in science education promoted personal relevance, recognition of science ideas in their daily lives, and positive affect (Heddy & Sinatra, 2012, 2013; Pugh et al., 2010; 2017). Similarly, the hands-on activities and reflection used in community-engaged learning has also been shown to prompt students to think about the real-world applications of their classroom knowledge (Markus et al., 1993; Strage, 2000). Thus, the community-engaged framework bolsters the Transformative Experience framework, and this study offers evidence of efficacy in promoting recognition and application of science ideas in daily life (See Table 11).

The research-based methods not only promoted recognition and application in students' daily lives, but also in within-class contexts, showing that these methods are effective in students' ability to transfer ideas to other classes (Table 12). However, the results of this study showed that students were not able to demonstrate their ability to apply science ideas in their writing. It is possible that more structured prompts or additional activities are needed for students to effectively display their application skills in writing. Some writing prompt suggestions from the literature are discussed in the limitations and future directions section.

Recognition and application of scientific ideas are important skills to consider developing in students due to the intersections between these abilities and scientific literacy. While there are many ways to describe science literacy, one definition relevant to this study is that "… the pursuit of science literacy is not *incidentally* but *fundamentally* about identifying relevance: learning to see how science is or could be significant to the things you care about most." [italics in original] (Feinstein, 2011, p. 180). The results of this study showing that students were better able to recognize and apply ideas in both the classroom and daily life, indicates the potential for these methods to increase scientific literacy among students. Scientific literacy is important because it helps cultivate adults who are prepared to gather insight from the world around them, identify misinformation, and make informed decisions (Sharon & Baram-Tsabari, 2020). This is especially important for students entering a world increasingly filled with different sources of misinformation, where they will have to make personal choices about important science-related topics, such as health decisions, voting, and environmental choices, among others. More than ever, it is important for education to help develop students' skills to think critically about the ways in which they can utilize their class knowledge to improve their future.

Field experiences promote students' positive view self-efficacy

As discussed in the prior section, the field experiences from the community-engaged framework were complementary to the Transformative Experience framework. However, another student outcome relevant to the conceptual framework of this study is the efficacy of the field experiences to promote positive views of self-efficacy among students. Student responses revealed that field experiences seem to be a powerful tool for impacting student understanding of science processes and feelings of belonging in STEM.

The optional open-response questions in the post-course survey students revealed some interesting insights. In responding to the question, “What was your favorite part of the field experiments?” two students responded in this way.

> [The field experiences] allowed me to better understand how scientists actually conduct experiments for research papers, which was cool.

> I enjoyed working together with my classmates and think it helped to make me feel comfortable having to work with others if I were to continue to do field experiments.

In their free-response answers, these two students described how the field experiences made them feel as though they better understood the process of collecting data for research, as well as helped them to perceive themselves as capable of undertaking scientific practices in the future.

Indeed, it appears that the experience in the course helped students to feel more confident about their ecological knowledge and skills. The quantitative survey results related to student connections, the survey question statement, “I have a strong background in Ecology.” revealed a significant increase (3.5 to 4.1; $p = 0.005$). These data point to an increase in self-efficacy, which is important because the *expectancy-value theory* (Eccles & Wigfield, 2002) explains that students will be more interested in and motivated to learn if they expect to succeed in the activity and see value in the idea or task. Thus, by increasing students’ feelings of self-efficacy, field experiences are a helpful tool to bolster student engagement with the course material. Indeed, many students remarked during their field experiences that they felt it was the first time they truly understood the efforts behind the many research papers that they have read for their classes. They also noted that it was the first time they were able to generate their own data, which they felt made the analysis process more engaging because they were invested in the results.

Making personal and social connections requires extensive reflection activity

The results of analyzing student writing showed that students were able to make more personal connections in their writing after the field experiences (Table 14). As well, open responses from student surveys revealed that their experiences seemed to positively impact their personal connections to the science ideas from the course. From the optional open-response questions in the post-course survey two students shared:

> Being able to learn about the environment around me and spending time outside really looking at what is around. [The field experiences] were one of my favorite activities I've done in college.
>
> [My favorite part was] seeing what we were learning about in real life!! I definitely felt as if I learned a lot by being in the field. I loved [the field experiences], I wish there could have been even more!

Even though students made significantly more personal connections in their writing, this trend was not reflected in the self-reported survey results (Table 3). As well, there was no significant change in the number of social connections made in the surveys or writing.

This study utilized ideas from prior studies that implemented communal utility value interventions. These studies have demonstrated the efficacy of these kinds of interventions for increasing motivation in first generation students and students belonging to minoritized groups in STEM (e.g., Brown et al., 2015; Canning et al., 2018; Harackiewicz et al., 2016). STEM is often thought of as being individually-focused and disconnected from community due to the normative description of science practices as independent and discovery-motivated (Estrada et al., 2018). Providing opportunities for students to make connections between the ideas they are learning in their STEM classes and their personal lives and communities helps overcome the un-communal reputation of STEM and helps underrepresented student groups feel that their values are acknowledged within the field.

However, students in the class did not increase their ability to make social or communal connections (See Tables 13 and 14). This may have been due to a myriad of factors, but one specific drawback was the structure of the course regarding writing assignments. The opportunities for students to make their own social connections to science ideas were primarily in the form of very short writing assignments. In fact, each of the individual writing assignments averaged only about 260 words. The longer written assignments were structured as group activities, where 3-5 students would collaborate on writing an 8-10 page lab report. This was an element of the course that was not able to be modified for this study. The individual written reflections used in this study were a highly-shortened version of self-generated, utility-value interventions, wherein students are asked to provide information about how the ideas in class can be useful to themselves or their community. Longer versions (1-2 page essays) of these kinds of interventions have been shown to be useful in promoting personal and social connections to course content (e.g., Brown et al., 2015; Canning et al., 2018; Harackiewicz et al., 2016). This issue and further suggestions to foster student connections are described in the following section.

Limitations and Directions for Future Research

Every study faces limitations that must be considered with any future research project. In this section, I focus on five limitations that likely impacted this study's results. First, the greatest imitation in this study was the sample size. Only two sections of the course are taught every other semester. The two sections studied for this project totaled 49 students, with 33 completing matched pre- and post- surveys and 44 completing matched pre- and post-essays. The small sample size limited the number of analyses that could be performed. A larger sample size may have allowed for more precision in analysis, picking up on any patterns between groups of students, or allowing for additional consideration of intersectionality. As well, if there had been a larger sample size of students available to study, I would have chosen to include a control group. A great deal could be learned from including a control group class that did not include the pedagogy utilized for the two sections of this course. By including one class as a control group and one class as test groups we could gain a more complete understanding of the degree to which the teaching strategies for the test groups are enhancing student outcomes beyond the “typical” level of student engagement.

A second large limitation was the structure of the existing course. One primary goal of the existing course was to prepare students to both understand and perform data collection and analysis. This is an important goal, as much of undergraduate education focuses on teaching the content rather than the methodology. However, because of this, the students spend a large portion of their time in the course collecting data and learning and performing multiple kinds of analyses on statistical computer programs. To offset the time students spend performing these activities, the main writing assignments are designed as group assignments, where students work together to write up their results and discussion. As a result, the time allotment for individual reflection and writing is limited. And in turn, the opportunity to investigate what individual students were learning or the connections they were making was limited.

It was clear from the statements that individuals offered that there is much to be learned from designing more opportunities for students to engage in reflection. The personal and social connection portion of this study may have been enhanced if the course was designed to include time in class for systematic reflection and writing, which could be easier to accomplish in a course less focused on learning and practicing STEM methodology. For this study, the methodology and framework of the course content, teaching strategies, and assignments were all connected to Transformative Experience and community-engaged framework whenever possible.

However, I believe that because there were fewer opportunities for writing, the goal for students to make connections was not able to be fully realized. In other words, students can be informed of the relevance and utility of ideas, but students can't make a connection to their own life without undergoing internal reflection.

Future research should be designed to include more balanced and systematic mixed methods, where students are provided in-class opportunities for reflection (e.g., weekly in-class journal entries, group activities where students dialogue about their reflections, etc.). This would allow for more opportunities for students to both develop and demonstrate these ideas. Two relevant methodologies for structured reflection activities from the literature include: letter writing and iterative reflection. Letter writing is a psychological intervention that can combine value-affirmation and utility-value treatments wherein students write a letter to themselves, or someone else, about their personal values and how the topics they are learning about in class are related to those values (see Casad et al., 2018 for a review of these kinds of interventions). Community-engaged or service-learning literature also suggests using iterative reflection or providing students with multiple opportunities to think about their role and connection to the community context (Felten & Clayton, 2011). By providing students with opportunities to reflect before, during, and after their hands-on experiences, they can better perceive how their knowledge and views have changed or expanded (e.g., Hullender et al., 2015). It is apparent that if social or personal connections are a primary goal of an intervention, then it is important to prioritize time for students to write reflection using carefully structured prompts.

A third limitation is related to the Covid-19 pandemic. This study took place in the Fall of 2021, and due to the pandemic, nearly all the public education programs had not yet resumed operation of in-person education assistance, particularly for facilitating group events. Many of the community partners that I reached out to regarding the potential to participate in this study lamented that they were not able to assist or participate more fully with the planned field experiences. Initially, to align more closely with the community-engaged framework, I planned to partner with each location to guide the community-focused process with students. With each location offering students a brief history and discussing both the community and ecological needs of the sites that each experiment would focus upon. However, the locations were not able to accommodate partnerships, so I had to improvise, and used the publicly accessible information to help the students connect with each site.

I believe that a stronger partnership with community locations would have helped students to better understand the connection between the science ideas and the local context. In fact, during this process I did make connections with the education department at the Tijuana River National Estuarine Research Reserve. While the location was not able to accommodate our group, they did assist one student group with their final project, where they chose to survey an invasive estuarine plant species in the reserve, and their experiment resulted in a compelling presentation for the final class. I believe this case shows that there may be opportunities in the future to partner with community locations, as many were eager to help but were limited by the global pandemic. As well, this study shows that, even in the absence of physical support, community locations can support education endeavors by providing online resources.

A fourth limitation of this study was related to what the results revealed about the high pre-scores. High pre-scores in this group of students may have shown a ceiling effect and limited the effectiveness of methodology to promote change. Thus, it is possible that this methodology may differently impact other student groups such as non-ecology/biology majors that may have lower pre-scores. It is possible that in a population with lower pre-scores in their recognition or connection to science ideas, this intervention may have been able to promote more change, as there is more room for improvement. To address this possibility, future research could implement these activities in a science course meant for non-STEM majors, or another context where science knowledge or connection to the content might be less developed.

A fifth limitation of this study was the fact that the two sections of the course were taught by two different graduate teaching assistants. Although both instructors adopted the field activities and writing assignments, the teaching approaches and level of adherence to the Transformative Experience teaching framework differed greatly between the two sections. One of the teaching assistants had more teaching experience, had instructor training in her previous graduate program, and was able to adopt the research-based teaching strategies more easily. While I was able to assist with teaching and did lead the field experiences, there is reason to believe that students may have had different experiences between the two teaching assistants. This may be amended in the future by taking more time for instructor preparation or having the same teaching assistant teach all sections. I also believe this limitation highlights the importance of instructor preparation. The teaching assistants both shared that they wished they had more instructional guidance in their current roles and were grateful to be introduced to research-based methods. However, even as both were eager to adopt the strategies, the instructor who had experienced teaching assistant preparation in her previous institution was much better able to implement the methodology. Thus, to effectively implement research-based suggestions, teaching assistants should be provided with at least a small amount of training or familiarization with common teaching strategies.

CONCLUSION

This study adds to the existing literature by demonstrating the effective implementation of Transformative Experience teaching methods alongside community-engaged field experiences in undergraduate STEM. The first guiding question was to investigate how these methodologies could combine to improve students' recognition and application of science ideas in their daily lives. This study confirmed that this combination of treatments is very effective in fostering students' recognition and application of science ideas in their daily lives. Students' self-reported recognition and application scores improved, bolstered by similar findings via quantitative and qualitative analysis of student writing.

The second guiding question aimed to discover how community-engaged field experiences impact students' connections to STEM. The findings indicated that although students were able to make more personal connections in their writing, their social connections did not significantly change. Although previous studies have found that women, first generation students, and traditionally minoritized groups in STEM tend to make more social connections when given the opportunity, this study did not replicate this finding. More extensive or more structured reflection activities may be necessary to promote more meaningful connections to the science content. This study also found that the hands-on activities seemed to positively impact student engagement and bolstered students' views of self-efficacy in STEM.

This study highlighted the value of integrating transformative and community engaged field experiences in biology education. Not only do these types of teaching methods create engaging and enjoyable learning environments for students, but they also appear to help students deepen their personal connections to science in the real world. This is especially important, as even when students engage meaningfully with their education, they often fail to transfer their knowledge to their own lives. Because our society must increasingly use many different sources of evidence to make decisions about science-related topics, helping students connect their classroom knowledge to their personal life can hopefully better equip them to make informed decisions.

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