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A female student's achievement emotions in an inquiry-based physics class

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Abstract

While student emotions influence student learning and engagement, there is a notable gap in our understanding of student emotions regarding science learning, particularly within the context of postsecondary science education and inquiry. The study investigated the types of emotions experienced by a female college student and their effects on her learning and engagement in an inquiry-based physics class. Student emotions were categorized into four types using the control-value theory. The findings revealed that empathy and praise, particularly concerning the learning process, were important in promoting positive activating emotions. On the contrary, negative emotional support from teachers could arouse the student's negative deactivating emotions, subsequently leading her to withdraw her engagement in learning activities. When emotions were associated with activation, either positive or negative, they had a positive effect on student learning, while deactivation emotions, particularly negative deactivating emotions, impeded student learning. The study emphasized the importance of empathy in learning, highlighting its capacity to convert negative emotions into positive ones.

Keywords: emotion, control-value theory, physics education

INTRODUCTION

Educational contexts abound with affective experiences for students (Fiedler & Beirer, 2014) as they encounter a range of emotions intertwined with their learning and engagement in learning activities. Science class is no exception, as students can experience various emotions. They may find enjoyment in their classes, feel excitement about science homework, and take pride in their achievements in learning science. On the other hand, they may experience frustration when conducting science experiments, become bored with their homework, and feel hopeless when facing tests.

While it may seem natural to perceive science learning as a cognitive process and emotions as temporal reactions to events, with negative emotions serving as impediments to learning and rational thinking, studies have revealed a more complex relationship between cognition and emotions. For example, not only cognition but also emotion is interconnected with students' success and persistence in STEM courses and degree programs (Raker et al., 2019). Furthermore, the relationship between cognition and emotion is bidirectional. That means that just as cognition can influence people's emotions, emotions can also affect people's cognition (Fiedler & Beirer, 2014).

Fortus et al. (2022) argue that *affect* should be considered alongside conceptual knowledge, as it significantly influences the learning and teaching of science. They also noted a significant oversight regarding affective characteristics in science literacy studies and various national curriculum standards. Affect is commonly used to denote a wide variety of noncognitive constructs such as emotion, self-concept, beliefs, motivation, etc. (Pekrun & Linnenbrink-Garcia, 2012) and in science education studies, there is extensive research on some constructs of affect, for example, students' interests, curiosity, and motivations. Nonetheless, the study of emotions in teaching and learning has been largely overlooked (Ritchie, 2018). In other words, there remains a notable gap in our understanding of student emotions related to science learning. Especially, lacking are studies focusing on students' emotions within the context of postsecondary science education and science inquiry (Bellocchi, 2018; Raker et al., 2019). Recently, there has been an emergence of research exploring the role of emotions in engaging learners in activities related to understanding science

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Contribution to the literature

- This study clarifies the positive impact of activating emotions on student learning.
- It highlights the crucial role of empathy and emotional validation from teachers and peers in helping students manage and transform negative emotions.
- Through a single student case, it offers deep insight into how emotions are shaped by interpersonal and contextual factors, pointing to future directions for group-based emotional research.

concepts (e.g., Gupta et al., 2018; Jaber et al., 2021a, 2021b). In particular, Jaber et al. (2021a) highlighted the importance of teachers' empathy in understanding students' epistemic and emotional experiences, connecting to the teachers' own prior experiences, and emphasized its importance in supporting students' disciplinary learning. However, addressing each student's emotions can pose challenges for teachers in a classroom setting. Given that students are able to closely observe their peers' emotions and easily interact with each other, especially in a group setting, peers' empathy related to their learning may also influence their learning and engagement in learning activities.

Why is it important to pay attention to students' emotions in a science classroom? Bellocchi and Ritchie (2015) noted that emotions displayed by students provide insights into their current level of conceptual understanding of science concepts. Therefore, educators should be attuned to student emotions to facilitate their learning in science better. In particular, understanding the types and effects of emotions pertaining to learning is essential for designing effective teaching strategies in response to student emotions. Therefore, the research questions guiding this study were as follows:

1. What factors influence students' emotions pertaining to learning within an inquiry-based physics class?
2. To what extent do these emotions impact student engagement in learning activities?
3. What is the role of epistemic empathy in students' learning and engagement in the physics class?

LITERATURE REVIEW

Control-Value Theory

Control-value theory provides a framework for understanding the structure of emotions and their interplay with control and value beliefs, particularly in the context of achievement emotions (Pekrun, 2006; Pekrun & Perry, 2014). Linnenbrink-Garcia et al. (2016) define control appraisal as the perceived ability to control actions and outcomes, while value appraisals refer to the subjective importance attributed to these activities and their results. Based on the theory, emotions can be classified according to their valence (positive/negative) and activation level (activating/deactivating). Valence distinguishes between positive states, such as enjoyment and pride, and negative states like anger and anxiety. In terms of activation, there is a distinction between activating states and deactivating states, such as excitement versus relaxation (Pekrun & Linnenbrink-Garcia, 2012). Pekrun et al. (2011) noted that while positive emotions generally enhance motivation for continuing academic tasks, certain positive emotions like relief can actually deactivate students' immediate motivation to continue their work. Likewise, negative emotions tend to diminish students' motivation, but some negative emotions such as anger and shame can induce strong motivation to overcome the negative events leading to these emotions and to avoid failures (Pekrun et al., 2002). Therefore, it is important to understand emotions not only in terms of positive and negative value but also in terms of activation and deactivation, especially in educational contexts. Pekrun and Linnenbrink-Garcia (2012) expanded on this notion, suggesting that positive activating emotions (e.g., enjoyment) improve the learning experience by enhancing students' interest in learning activities, motivation for engagement, and utilization of deep learning strategies and self-regulated learning. In contrast, negative deactivating emotions (e.g., boredom) impede student learning, aligning with the conventional understanding of negative emotions' impact on learning. Pekrun (2006) provided examples of emotions in each category (positive activating: enjoyment, hope, pride; positive deactivating: relief, relaxation; negative activating: anger, anxiety, shame; negative deactivating: hopelessness, boredom). Fong and Schallert (2023) advocate categorizing emotions into two dimensions, positive or negative, and activating or deactivating, instead of relying solely on discrete emotion types in educational research as this approach offers a more efficient and flexible method for studying emotions within the context of learning.

Achievement Emotion

The learning science is often viewed as a cognitive process and outcome, with emotions considered as temporal reactions to events; and negative emotions can pose a hindrance to learning and rational thinking. The study focused on the achievement emotions that students experience in the classroom setting. Drawing guidance from the extensive research conducted by Pekrun et al. (2011) on achievement emotions (Pekrun, 2006; Pekrun & Linnenbrink-Garcia, 2012; Pekrun &

Stephens, 2010), the author aimed to better understand and interpret students' achievement emotions during their academic pursuits. Achievement emotions are not only related to the success and failure outcomes of learning activities but also to academic activities such as studying and taking exams (Pekrun & Linnenbrink-Garcia, 2012). Pekrun (2006) introduced the concept of achievement emotions, distinguishing between momentary occurrences in a given situation (state achievement emotions) and an individual's habitual and recurring emotions (trait achievement emotions) in relation to achievement *activities* and *outcomes*. In particular, trait achievement emotions can be situation specific; for example, students may have habitual emotions related to physics in physics-related situations. This suggests that certain subjects can trigger students' achievement emotions, leading to the automatic and non-reflective induction of emotions based on recurring, conscious appraisals. Consequently, appraisals and achievement emotions become routinized, and conscious regulation of emotions is diminished (Pekrun & Stephens, 2010).

Connecting control-value theory to achievement emotions, it's important to note that not all positive emotions have a positive impact on students' achievement. For example, positive activating emotions, like enjoyment, can have a beneficial influence on students' intrinsic motivation, their relational processing of information, their learning strategies, and self-regulation, thereby enhancing students' performance and learning outcomes. On the other hand, positive deactivating emotions, such as relief and relaxation, can reduce attention to the task and lead to superficial information processing. Pekrun and Linnenbrink-Garcia (2012) considered *engagement* as a mediator between emotions and achievement, indicating that emotions influence students' engagement, which subsequently affects their achievement. Pekrun et al. (2017) delved further into investigating the causal relationship between emotions and achievement by examining multiple data points over several school years in students' development in mathematics. Their study highlights a reciprocal relationship between emotions and achievement rather than a unidirectional one (i.e., emotions affecting students' learning and performance, and vice versa).

Student achievement not only affects their emotions, but the learning context also has an influence on their emotions. For example, different subjects or specific content topics can affect student emotions. Moreover, the structure of tasks and the clarity of instruction, including feedback, can further influence student emotions (Fong & Schallert, 2023; Pekrun & Linnenbrink-Garcia, 2012). For instance, tasks in an open-ended format often induce high levels of anxiety. Similarly, tasks with high demands but lacking clear instructions can instill a sense of diminished control in students, resulting in heightened anxiety. Conversely, low-demand tasks may elicit feelings of boredom. This suggests that clear instructional and structured task formats positively impact students' emotions and engagement, particularly when cognitive incongruity is minimized (Pekrun & Linnenbrink-Garcia, 2012).

Moreover, a student's self-concept plays a role as a mediator in the relationship between achievement and emotion (Pekrun, 2006). Students naturally assess their abilities based on their task performance, and their perceived ability, reflected in their self-concept, can strengthen positive or negative achievement emotions (Pekrun et al., 2019). Additionally, a student's self-concept within a specific discipline (e.g., physics) significantly impacts their future performance in that discipline (Marsh et al., 2002), potentially affecting their perceived identity within the disciplinary field. This disciplinary identity, in turn, influences their career choices and future achievement (Hazari et al., 2010). While students' interest in science is recognized as an important component of their science identity, their achievement emotions in science have been relatively overlooked as a factor shaping their science identity.

Student Emotion Studies in Science Class

While students' interests, curiosity, and motivations in science have been extensively studied, there remains a notable gap in our understanding of their emotions related to science learning. Recently, there has been an emergence of research focusing on how emotions contribute to engaging learners in science activities and interacting with scientific concepts. For example, Gupta et al. (2018) explored the impact of learners' emotions on their understanding of physics concepts and the cognitive processes involved. They presented a case illustrating how a student's epistemological stance and emotions shifted together. Initially, the participant expressed negative emotions towards idealized circuit models due to her perception that they were not relevant to her professional goals. However, her emotions shifted positively as she found enjoyment in solving circuit problems, leading her to reconsider the usefulness of idealized circuit models for problem-solving. While Gupta et al. (2018) did not find concrete evidence to support integrated emotional-cognitive dynamics over the view that emotions are merely epiphenomenal, their study suggests that emotion shifts occur in conjunction with shifts in epistemological stance. Jaber et al. (2021b) emphasized the role of affect in learning science, especially through hands-on scientific inquiry. They reviewed studies concerning the role of effect on scientific inquiry in face-to-face settings and concluded that these studies offer solid evidence to support learners' affect as an integral part of scientific explorations and a driver of epistemic pursuits. They posited that online learning environments might lead to different dynamics between affect and scientific inquiry

and investigated teachers' affective expressions and the functions of these expressions in online scientific inquiry. Their findings indicated that affective expressions increased interactions among students and fostered the establishment of an online learning community where they could assist each other in understanding the phenomena and engaging in scientific practices.

Teachers can use students' emotions as indicators to recognize their progress in understanding concepts. Bellocchi and Ritchie (2015) focused on emotional events that occur during scientific inquiries as moments when student achievement emotions could parallel their conceptual changes. One such event involved a student experiencing frustration and anger when the student perceived his ideas were being rejected. However, as his teacher facilitated his learning through follow-up questions, he eventually succeeded in explaining the observed scientific phenomena, which led to a transformation of his negative emotions into positive ones, such as pride. This finding suggests that students' displayed emotions serve as indicators of their conceptual understanding at the moment, emphasizing the importance that teachers attend to students' emotions to help them in their science learning. As Ritchie (2018) pointed out, "research on emotions in learning and teaching has historically been overshadowed by a cognitive focus" (p. 5). Therefore, there is a need for further study on students' emotions.

METHODS

Research Context

The research was conducted in an inquiry-based introductory physics class at a large research university in the USA. The physics class had no traditional lectures but followed an inquiry-based approach, especially the Socratic method of inquiry. The Socratic method of inquiry, which is recognized for promoting self-directed learning and critical thinking (Wang, 2010), is characterized by its emphasis on dialogue and questioning to facilitate the exchange of ideas and suppositions (Miller, 2008). In the physics class, there was one instructor and four learning assistants (LAs) who circulated to help when students needed help. Since there were no lectures, the LAs' role mirrored that of the instructor during class; therefore, the study referred to both LAs and the instructor as teachers. Students were grouped in the classroom, with four or five students working together. No physics textbook was required; instead, students were told to get a workbook made specifically for the class. Each section of the workbook had experiments, questions to answer based on those experiments, checkpoints for students to confirm their answers with teachers, and extra exercise questions.

Participant

Given the complexity of emotions and learning dynamics, a single-participant study design allows for a granular and comprehensive analysis of how one student experiences and navigates emotions while learning disciplinary knowledge and skills. Therefore, we adopted a case study approach, enabling an in-depth exploration of an individual's experiences (Yin, 2018) in an inquiry-based science classroom, particularly given the limited understanding of students' emotions in physics classes. Educational research has employed single-case studies to uncover nuanced, context-dependent insights (Stake, 1995), contributing to theoretical generalizability by identifying key themes and understanding individual experiences in real-world settings, which can be applied to a wider population (Flyvbjerg, 2006).

Samantha (pseudonym), a senior female student, who volunteered to participate in the study. She transferred from a community college to the research university with plans to pursue a graduate program in one of the science disciplines. During her first interview, she mentioned feeling greater fear in mathematics than any other subject and that this led her to postpone taking the introductory physics course until her final year of college. Her career goal was to become a college professor at a community college. She had never taken a physics course before, not even in high school, so this was her first introduction to the subject. Samantha's case is critical to this study because introductory STEM courses, including physics, are often perceived as gatekeepers or weed-out courses and have been flagged as potential sources of inequity (Chen & Soldner, 2013). In the USA, taking physics in high school is not mandatory, yet many college STEM degree programs require students to complete an introductory physics course. As a result, it is not uncommon for students who did not take high school-level physics to enroll in introductory college physics courses. These introductory STEM courses play a critical role in shaping the career pathways and degree attainment of students pursuing STEM-related majors. However, success rates in such courses are often low, particularly among students from marginalized backgrounds (Hatfield et al., 2022). Therefore, Samantha's experience is not an isolated case but rather representative of a broader group of students who face academic struggles and marginalization within educational settings.

Data Sources

Student interviews served as the primary data source, supplemented by additional data including classroom observations, the researcher's field notes, and student emotion diaries. The author observed the class five times over a three-week period and conducted weekly interviews during this time, with each interview

lasting approximately 60 minutes. The participating student was also asked to write emotion diaries reflecting her emotions during each observed class. These diaries prompted her to indicate and explain her emotions during the lesson. Since five classes were observed, five emotion diaries were collected. To minimize classroom distractions, the physics class itself was not audio- or video-recorded; instead, the author relied on personal observation and note-taking. Prior to each interview, the author reviewed the student's emotion diaries along with the field notes to develop post-lesson interview questions. For instance, the participating student was asked to elaborate on why she felt the emotions as indicated in her diaries or on what the author had perceived during the class. The interviews were recorded in voice format only and later transcribed verbatim.

Coding and Analysis

When analyzing interview transcript data, the author read the transcripts line by line and initially coded them, paying attention to expressed emotions related to the student's physics class, such as group members, teachers, learning activities, learning materials, tests etc., using qualitative analysis software, MaxQDA 2022. Then, the author reread the transcripts and categorized codes into four types of emotions: positive activating, positive deactivating, negative activating, and negative deactivating, based on control-value theory (Pekrun, 2006; Pekrun & Perry, 2014). The study involved various forms of data, such as interviews, journals, and field observations (Creswell, 2013), and iteratively refined codes to ensure credibility (Creswell, 2016; Guba, 1981). While inter-rater reliability was not established due to the fact that data analysis was conducted by a single researcher, the analysis was structured and guided by an established theoretical framework, control-value Theory (Pekrun, 2006), which provided a consistent lens for identifying, categorizing, and interpreting codes across the data. This deductive coding approach contributed to analytical coherence and helped reduce subjective bias during interpretation.

FINDINGS

The physics course was structured to foster students' self-directed learning and critical thinking via the Socratic questioning strategy. Students were tasked with understanding and applying physics concepts by conducting scientific experiments as the course workbook requested. In the findings section, Samantha's achievement emotions related to her learning physics were examined through the lens of the control-value theory framework (Pekrun, 2006; Pekrun & Perry, 2014).

Positive Activating Emotions

Instances of her positive activating emotions were linked to positive interactions with teachers, positive self-appraisal of her learning, and her interest in specific physics topics.

Positive interaction with teachers

> "[T]he classes where I was emotionally supported, those were the ones I did really well" (interview #1).

In typical classroom settings where interactions between students and teachers happen, emotions abound. Samantha experienced positive emotions with teachers such as encouragement and enthusiasm towards learning physics when teachers provided verbal affirmations and praise. For example, in her emotion diary, she wrote,

> "I felt enthusiastic for a brief moment when [teacher B] gave me verbal praise for understanding something (even though it's probably an understanding that's rudimentary). I really do strangely thrive on verbal praise" (from emotion diary #4).

Teachers' empathy towards her learning also played an important role in fostering positive emotions in learning. Samantha remarked,

> "[Teacher C] doesn't make you feel stupid for not knowing something" (from interview #3).

Further, she said

> "I think more positive, less frustrated for sure. And when I'm less frustrated, I definitely learn the concepts better" (from interview #3).

That quote highlights how her emotions influenced her learning in her physics class.

Noticeably, the expectation of positive interactions with teachers, even without actual interaction for that moment, elicited positive emotions about her learning. She expressed a feeling of hope derived from her belief that teachers with whom she had previous positive interactions would help her study:

> "That's the only reason I have a glimmer of hope in the class. It's because [teacher B and teacher C] and like they all do office hours and they help you with the homework and they give us guidance there" (from interview #3).

These positive emotions enabled her to continue engaging in dialogue with the teachers, which was an essential component in the Socratic questioning-based course. Conversely, when her expectations were negative, she refrained from interacting with the

teachers, as discussed in the sections addressing negative emotions.

Positive self-appraisal of learning

Not only did the teacher's affirmation of Samantha's learning affect her emotions positively, but her positive self-appraisal also influenced her positive activating emotions in learning. When Samantha positively recognized her own learning progress, she experienced positive activating emotions. For example, when she successfully applied a physics concept to explain everyday scientific phenomena, she felt that

> "[the experience] was awesome" (from interview #3).

Furthermore, this emotion influenced her to see herself as becoming a physics person:

> "The other day something fell out of my fridge, and like oh, I wonder if there was more friction if it wouldn't have fallen. And then I was like 'Who am I?' [she laughed]. So, so I think I am becoming more of a physics person" (from interview #3).

Topic emotions

The third case occurred when certain physics topics triggered Samantha's positive activating emotions. During the first interview, she expressed negative emotions about physics, even mentioning that she did not like physics before enrolling in the course:

> When I was signing up for my biology major, I looked at all the classes required for the requirements, and I saw physics and organic chemistry and it almost change my major. 'Cause I just knew, I know my strengths academically, and that's neither of those things are. So I guess my feeling about physics is that it's hard and I dreaded it from the beginning. And it's proven to be exactly what I thought it would be (from interview #1).

While Samantha repeatedly expressed her negative emotions toward physics, her positive activating emotions regarding certain physics topics emerged:

> "Today in class, I drew a force body diagram about a fan cart on a track and talking those concepts out with [teacher A] was really interesting" (from emotion diary #2).

When following up on her diary during the second interview, she mentioned:

> "I do like, like the force diagrams. That's really cool to like, think about how a person sits in a chair and what force is, is affecting them."

Before mentioning this, she explained that she was attempting to develop a general liking for physics, despite still experiencing significant anxiety with math, recognizing that positive emotions aided her learning process:

> You can't learn something you're not interested in. Like, if I listen to a song I like for the first time and I, I love it immediately, I'll remember half the lyrics, the first time I listen to it. But if I, I don't really like a song, I might never learn the lyrics. So, I think it's the same with classes and hard topics, you, you have to like what you're doing to remember it well (from interview #2).

This quote highlighted that students' emotions regarding a discipline as a whole could differ from their emotions concerning specific topics within that discipline.

Negative Activating Emotions

The study found that Samantha's fear of failing and struggles to understand physics concepts significantly influenced her motivation to invest effort in learning the subject.

Fear of failing

Fear of failing in a course could deter students from engaging in learning. However, this study found that it could also serve as a source of motivation for them to overcome the feeling. Samantha mentioned that she feared failing in the course, and that feeling that motivated her to do extra work and put in additional effort to overcome the negative emotion. For example, when the author asked her about her emotions related to learning and how they affected her learning, she said she often found herself in situations where she was failing and lacked emotional support from teachers in class. In response, she studied harder to demonstrate her capabilities to her teachers. Further, she confirmed,

> "So I guess it's the wanting to avoid failure at all cost that makes me do all these extra things. I think yeah, emotions and negative emotions can be very motivating sometimes" (from interview 3).

Experiencing difficulty in understanding physics concepts

When a new physics concept is introduced, it can be frustrating, especially when a student struggles to understand it. However, this study found that such moments could promote motivation to invest extra effort to overcome negative emotions.

> The author: How do you deal with that emotion [frustration over not understanding the concept], or who helps you?

> Samantha: Yea, I think I helped myself only. Um, and then being friends with the people in the class helps, but I think I've started just reading ahead in the lab manual. And I actually bought a textbook from another class to help me in this class. And then I have some idea of the concept before I come to class, and then I actually learn properly…a little bit better. So me doing extra work that they say is not needed, has helped me actually do.
>
> The author: But [its results are] really positive [for your learning], because of your negative feelings.
>
> Samantha: Yes, it's motivating (from interview #3)

As Samantha mentioned, not all negative emotions were detrimental to her learning; rather, they could provide motivation to exert extra effort.

In addition, Samantha confirmed the positive effect of negative emotions;

> "I think if I feel really positive about something, I might not try as hard. So I think maybe sometimes negative feelings and negativity actually help. 'Cause I really want to do well" (from interview#3).

Note that a clear instance of positive deactivating emotions was not found. However, what Samantha referred to as

> "feeling really positive about something, I might not try as hard"

might be an example of emotions that positively deactivate, potentially being detrimental to student learning.

Negative Deactivating Emotions

Samantha shared her classroom experiences, expressing feelings of lacking or experiencing negative emotional support, along with her persistent math and test anxiety, and how these factors impeded her learning.

Lacking or experiencing negative emotional support in classrooms

When students experience a lack of emotional support or negative emotional support in classrooms, it can impact their engagement in learning activities. Samantha's feeling of inadequacy in her physics class became evident when she felt disrespected or emotionally unsupported by her teachers, resulting in her withdrawing interaction with teachers. This experience had the effect that she was reluctant to seek guidance or feedback from the teachers. Moreover, she expressed that she would feel even worse if she were to seek help from them. Therefore, she did not even want to try, indicating that these negative emotions affected her in a way that disengaged her, particularly in her interaction with teachers.

> Um, but I do feel like, I don't know, sometimes when I ask questions in class, the response I'm given is kind of a little bit cut down or like why don't you get this? Or that's kinda just the feeling that comes along with it and maybe I'm being a little sensitive. Because I feel inadequate in my, with my performance in the class already…. But sometimes in class, I almost don't wanna talk to [Teacher A], 'cause it's a little, um, not intimidating, but just I don't think I'm gonna get a helpful answer sometimes. So it's almost like I don't want to ask. But then I'm lost on my own too. So, I can never really find a good balance, but yeah (interview #1).

Samantha shared similar instances where she felt discouraged while interacting with teachers in her emotional diary:

> This is my first physics class ever, so being left to think deeply over concepts I do not understand only furthers my anxiety. Also sometimes the way the teachers respond to my questions makes me feel like I'm an idiot for not understanding everything immediately. I don't think they mean to discourage questions, but they often do (from emotion diary #1).

Math and test anxiety

Samantha's test anxiety had a detrimental impact on her ability to engage in learning both before and after the test. Student test anxiety, especially before tests, has been extensively studied in previous research. Samantha also expressed her test anxiety, particularly regarding math and physics tests. Noticeably, the current study found that test anxiety negatively impacted her even after the test. Specifically, interviews with Samantha revealed that the anxiety persisted even after the test:

> I took this test last night and I just knew based on my understanding level, it was going to be bad. So I was crying on my couch and I couldn't eat. And then I had … I couldn't breathe at one point, I was just having to like really force myself to stop studying for like an hour (from interview #3).

Samantha's feeling of hopelessness regarding physics tests was evident because she couldn't anticipate improvement in the next test. The main reason for this was the disconnect between how she learned and how she was tested, which led to her feeling hopeless:

> I'm trying, but I don't think my grades reflect that, and we often get, um, talk, like talking to in class over our poor test grades. And that's frustrating

> too because I'm doing all I can, and I'm still failing. So, I don't know (from interview #1).

Samantha's math anxiety also played a deactivating role in her efforts to learn; as she said:

> I think I tend to put things off and then not think about things, and then put it off, and then do my other work that I am better at, or that comes more easy. And then, yeah, I get very stressed when I'm studying for the test, because I put it off for a few days when I should have been studying the whole week… The math still gives me anxiety and then I put off studying (from interview #2).

Samantha's struggles with math anxiety and lack of confidence in the subject undermined her sense of adequacy in the class, making her feel incapable of contributing to her group. In her first emotion diary entry, she expressed frustration at difficulty understanding math and physics concepts and that this intensified her feelings of inadequacy in the class. Additionally, during her first interview, she explained how this frustration arose from her perceived inability to contribute effectively to her group's learning activity, leading her to feel useless in her group. These findings show that when students lacked confidence in a subject and felt unable to contribute to group work, it exacerbated their sense of not belonging in the class.

Fostering Group Camaraderie

> I feel enthusiasm [about learning physics] at times because of our fun group dynamic and the friendships I have made in class. I genuinely enjoy my group. The four girls have become like friends and they help me so much to understand the math and to take things less seriously (from emotion diary #1).

During Samantha's first interview, she spoke about her group, saying,

> "I think we really do uphold each other emotionally. And through friendship, too, which is the only reason I'm doing moderately well."

Her group comprised five female students, including herself, and it provided her with a safe space to share her uncertainty in understanding physics concepts and to seek help to better understand and solve problems in physics. She attributed this sense of security to the fact that

> "they don't judge me for it" (from interview #1).

How did this group's dynamic develop? Samantha elaborated,

> "[T]here's like a certain camaraderie and bonding that comes across from suffering together. Yeah, so we're all suffering equally" (from interview #1).

By sharing challenges and negative emotions related to learning physics with her group members, Samantha gained a sense of safety and mutual support. No one was singled out when sharing negative feelings in her group, indicating that the shared experience of negative emotions pertaining to learning was critical in creating this safe and supportive learning environment:

> Like she [a student in her group] is the one that understands [physics] the best out of us, right? She told me something about being so frustrated with last week's homework she wanted to throw it against like a wall or something. And I'm like, "I understand, me too." So we're all suffering together which is good (from interview #1).

Not only sharing negative emotions in learning, but also demonstrating empathy was crucial in fostering a supportive and safe group atmosphere:

> I think everyone in our group cares very much about their individual performance, but also I think we've built enough of a friendship to where we all care for our struggling too … There's just a certain amount of, uh, bonding that we've gone through because we're also frustrated all the time. But um yeah. Like I think even though I obviously don't understand all the time, I feel like it's a safe environment to express my uncertainty (from interview #1).

In her final interview (interview #3), Samantha confirmed that building friendships had indeed made it easier for her to share her conceptual understanding and ideas to perform experiments and to solve physics problems, as well as to seek help from her group members without hesitation:

> "I think because we formed that friendship that we have in our group, it helps a lot to just talk freely, for sure" (from interview #3).

Despite experiencing math and physics anxiety, as well as a lack of confidence in these subjects, which led her to feelings of inadequacy in the class, Samantha actively participated in her group activities. She did not shy away from interacting with her group members. Emotional support such as empathy from her group members positively influenced her engagement in learning activities.

DISCUSSION

The study investigated a female student's emotions in an inquiry-based physics class. It delved into the

factors that influenced her emotions and subsequently how these emotions impacted on her learning and engagement in the classroom. Furthermore, it explored the role of teachers' and peers' empathy in her learning and engagement. Using the control-value theory (Pekrun, 2006; Pekrun & Perry, 2014), the study categorized the participating student's emotions into four types and explored factors influencing and the impact of these emotions. The four emotions were positive activating, positive deactivating, negative activating, and negative deactivating emotions. While categorizing the student's emotions, a clear case of positive deactivating emotion (e.g., relaxation) was not identified. This absence could possibly be attributed to the data collection period, which coincided with the middle of the semester, involving three class sessions per week and a midterm exam. Consequently, the student consistently engaged in new learning activities and test preparation during the study period.

In the study, positive activating emotions were identified:

(1) when the participating student had positive interactions with teachers, particularly when teachers affirmed her learning or showed empathy towards her learning,

(2) when she positively recognized her learning process and outcomes, and

(3) when she found a particular physics topic intriguing.

Specifically, Samantha felt enthusiastic when her teacher praised her understanding of a physics concept. Enthusiasm is an example of positive activating emotion as it is both positive and promotes motivation in students' learning and engagement. This positive activating emotion was attributed to the process-related praise provided by the teacher. Studies have found that process-related praise motivates students more effectively than praise focused on personal attributes (Haimovitz & Corpus, 2011). Process-related praise pertains to a person's learning strategy or effort, whereas person-related praise focuses on a person's ability or intelligence. The study found that not only process-related praise, but also teachers' empathy for her struggles in learning physics contributed to Samantha's positive activating emotions. These emotions, in turn, enhanced her learning experience. For example, Samantha shared her previous classroom experiences where she performed well because she felt emotionally supported. Self-appraisal of her learning was another attribute of her positively activating emotions, especially when she could explain a scientific phenomenon using a concept she had learned in physics class. That experience and emotions contributed to her identity as a physics person, as she increasingly recognized herself as such.

Despite Samantha's negative emotions towards the discipline as a whole, her positive emotions towards specific topics helped her realize that positive emotions enhanced her learning process. This recognition further motivated her to develop a liking for physics that helped her to excel in her physics class. As such, students may have different emotions toward specific topics than toward the discipline as a whole. Topic emotions are those experienced by students in relation to a specific subject within a domain of study, which may differ from the emotions experienced by students within the same learning environment (Broughton et al., 2013; Pekrun & Stephens, 2010). Pekrun and Linnenbrink-Garcia (2012) mentioned that topic emotions are epistemic in nature, triggered by both the characteristics of the information to be learned and the processing of that information. This study found that Samantha generally had negative emotions toward physics, yet specific topics within physics influenced her positively activating emotions. It was interesting that she described how well she remembered the lyrics of a song she liked, emphasizing that we learn better something that we are interested in. This case highlights how topic emotions influence student interest in the subject and their willingness to engage with it.

Samantha's negative activating emotions were found when she felt a fear of failing in the course and encountered difficulty understanding physics concepts. While negative emotions in learning might typically be viewed as detrimental, in cases of negative activating emotions, they could actually promote Samantha's motivation to overcome those negative feelings in her learning process. Samantha invested her time and money in additional efforts, such as dedicating extra study time, enrolling in an online class, and purchasing physics textbooks that were not even required for her class, all in an effort to avoid failure and gain a better understanding of physics concepts. Therefore, negative activating emotions could strengthen students' motivation to learn better and do well in class (Pekrun et al., 2002).

Conversely, when negative emotions are associated with deactivation, they could impede students' learning. Such cases were identified when Samantha perceived negative emotional support from her teachers, such as disrespect or ignorance, which led to her withdrawal or reluctance to engage with them. Additionally, her enduring feelings of anxiety and hopelessness regarding math and tests had a detrimental impact on her engagement and confidence in learning. Her lack of confidence led her to doubt her ability to learn or to invest effort in studying and even to feel that she did not belong in her class. Notably, her test anxiety continued to affect her even after completing her tests. Indeed, these emotions did not contribute positively to her learning and engagement, and when working in isolation, those emotions persist without improvement. In the study, her group played a significant role in transforming those emotions into positive ones.

Specifically, the shared negative emotions among group members and their expression of empathy related to their learning were crucial in the process. Samantha referred to her group as her comrades. Within the group, she felt comfortable sharing her struggles, frustrations, anxiety, and ideas to solve physics problems, even though she was not certain if that was a normative idea. She was not the only one experiencing those negative emotions, and through sharing and caring for each other's emotions, her group created an environment where students could actively engage in learning and scientific activities. Therefore, validating learners' negative emotions pertaining to learning and showing empathy toward those emotions were important attributes in creating an environment where students felt safe and could experience positive activating emotions that motivated learning (for example, "*I feel enthusiasm at times because of our fun group dynamic and the friendships I have made in class,*" as mentioned in Samantha's emotion diary). Therefore, this study claims that group functions and interactions with peers and teachers could be positive when empathy abounds in classrooms. Emphasizing empathy in classrooms has been mentioned in previous studies. Sadler and Zeidler (2005) emphasized empathy as an important attribute for facilitating student engagement in learning, as it allowed students to understand the feelings and thoughts of others by experiencing how they felt. Importantly, the current study connected a student's emotions, categorized into four types, and explored how empathy affected their emotions and learning, including their engagement. Jaber et al. (2021b) also emphasized that sharing emotions among peers, whether positive or negative, ignited students' inquiry in science class. Therefore, affective expressions among students play a critical role in connecting them to shared epistemic goals and their related practices. Consequently, the current study suggests that negative emotions, whether persistent or temporary and whether deactivating or activating, should be acknowledged and addressed within educational settings through empathy. Teachers and peers are the ones who can demonstrate this empathy in classroom settings.

In summary, the findings revealed that empathy and sharing emotions, particularly concerning the learning process, are important in promoting positive activating emotions. On the contrary, negative emotional support from teachers could arouse students' negative deactivating emotions, subsequently leading them to withdraw their engagement in learning activities. As such, some of the emotions positively affected learning, such as boosting students' motivation, while others were detrimental to learning. When emotions were associated with activations, whether they were positive or negative, they had a positive effect on student learning while deactivating emotions, particularly negative deactivating emotions, impeded student learning. That implies that as an educator, fostering activating emotions should be a priority to enhance students' learning. In this regard, the study found that sharing negative emotions was important, and validating those emotions by teachers and peers was critical in creating an environment where students could shift their emotions toward activating ones and enhance their engagement in class.

Lately, there has been increasing attention on the emotional aspect of student learning, as emotions are known to play a significant role in driving engagement and facilitating effective learning. The study contributed to the literature with evidence showing how student emotions were associated with various factors, such as teachers and peers, disciplinary contexts, specific topics within the discipline, self-appraisal of learning, and persistent emotions. It also explored how these emotions could have influenced student learning and engagement. Furthermore, the study highlighted the significance of empathy in learning.

A limitation of the study is that the study focused on only one case of a student who had experienced fear of mathematics. Therefore, future studies should focus on exploring the dynamics of various student traits within group settings and how emotional events, such as positive or negative interactions with teachers, affect their emotions differently. Additionally, it would be interesting to investigate how students within the same group perceive their group dynamics similarly or differently and how these dynamics impact their emotions and learning engagements. This would provide a better understanding of students' emotions and inform pedagogical approaches for teachers to effectively respond to different student emotions within the same context. We believe such research will enhance our understanding of student emotions and their effects on learning and engagement and guide pedagogical strategies to foster activating emotions.

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