American Journal of Qualitative Research[1]
2026, Vol. 10 No. 1, pp. 109-122
https://doi.org/10.29333/ajqr/17418

AMERICAN JOURNAL OF QUALITATIVE RESEARCH
ISSN: 2576-2141

Perceptions of Student Success in Post-Secondary Chemistry Courses

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ABSTRACT
Chemistry is the foundational course for any science major, as well as many post-baccalaureate programs. However, chemistry courses in higher education are considered highly impacted and continue to have high failure rates every semester. Current research in science, technology, engineering and mathematics (STEM) education identifies those students struggle due to their reliance on memorization to understand foundational concepts. Not much is known about what successful students have experienced, the development of their STEM identity, or their methods of studying. The present qualitative study explores how four successful students negotiated key bonding concepts in general chemistry and how these experiences shaped their STEM identity and self-efficacy during the COVID-19 era of online learning. Semi-structured interviews were analyzed thematically using grounded theory, with member checking, triangulation of artefacts, and an audit trail to enhance trustworthiness. Three major themes emerged: (a) positive experiences that sparked engagement, (b) strategic independence that bolstered confidence, and (c) instructional strategies (visualization, depth of explanation, authentic problems) that students found most helpful. Implications for equity-oriented pedagogy and universal design for learning (UDL) in chemistry are discussed.

KEYWORDS: Chemistry, student perceptions, influences, positive experiences

Over the past two decades, international calls to improve STEM retention have intensified (National Academies, 2022). In the United States, fewer than 40 % of students who enter university intending to major in a STEM discipline ultimately earn a STEM degree (Chen et al., 2021). General and organic chemistry remain pivotal "gatekeeper" courses with failure and withdrawal rates of 30–50 % (Towns & Cole, 2023). Historically marginalized students,—women, first-generation, and racially minoritized learners,—continue to report chemistry as a primary driver of attrition (Raker et al., 2023). Contemporary scholarship therefore calls for research that centers student voice, identity, and agency when investigating success in chemistry (Cooper & Stowe, 2022; Pawlak & Barbera, 2024).

The National Science Foundation's 2030 Vision emphasizes increasing diversity and persistence in STEM fields, with chemistry listed as a high-priority bottleneck (National Science Foundation [NSF], 2023). Parallel policy documents from the American Chemical Society (American Chemical Society [ACS], 2022) urge instructors to adopt evidence-based, inclusive pedagogies. Understanding what successful students perceive as supportive is critical for designing such interventions.

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Relevant scholarship research underscores the role of self-efficacy (Bandura, 1977) and STEM identity (Stewart, 2022) in persistence. Recent empirical studies (Ferguson & Martin, 2022) indicate that mastery-oriented feedback, culturally relevant examples, and explicit metacognitive training can boost student confidence and achievement in first-year chemistry. However, few studies have qualitatively examined how students experience these supports during the transition from general to organic chemistry - particularly in pandemic-induced online environments.

Across modalities, students' success is shaped by the supports that surround them. In online doctorates, a meta-synthesis highlights cohorts, mentoring, and flexible access as key enablers, with isolation and work–family–school conflicts as persistent risks (Akojie et al., 2019). Synthesis of online doctoral research highlights recurring success levers,—responsive advising, peer community, writing and library support, and explicit time-management scaffolds,—mirroring factors that our participants credited for confidence and persistence (Akojie et al., 2019). Advising quality is another institutional lever: graduate students call for a more explicit professional pathway that equips advisors with foundational training and practice to influence retention and achievement (Houdyshell & Kirk, 2018). Beyond discrete services, socialization into the norms and values of schooling,—enculturation—,emerges from the interplay of family and school experiences (Dogutas, 2020), suggesting that programs should treat advising, mentoring, and cultural socialization as a connected ecosystem rather than siloed interventions.

Equity issues in higher education are fundamentally structural rather than individual. The pandemic further revealed how gendered expectations and fragile support structures constrain scholars' productivity and wellbeing, especially for mother scholars (Platt et al, 2022). Seen alongside research on how students internalize cultural norms through school–family enculturation (Dogutas, 2020), these accounts point to the reproduction of inequities through everyday practices, underscoring the need for systemic redesign of policies, workloads, and supports.

Longstanding inequities in chemistry education reach across race, gender, and class (Morales-Doyle, 2017). Morales-Doyle notes that inequities across these identities remain prevalent and under researched. He calls for curriculum reform for more justice centered pedagogy in the sciences. The reform presented by Morales-Doyle can be addressed by understanding the negative experiences of students in underrepresented groups. Organic Chemistry is a higher education course that brings with it negative connotations. By identifying students' perceptions and experiences in previous courses, educators may be able mitigate low self-efficacy and enhance student experiences. The goal of this study is to uncover the positive experiences students had involving foundational topics in chemistry which could aid in the development of new pedagogical approaches. Positive experiences have been shown to increase student self-efficacy levels in multiple higher education subjects (Ertmer et al., 1994; Van Dinther et al., 2011).

Theoretical framework

STEM identity is the personal and community recognition of one's abilities to be a valuable member of the STEM community. STEM identity framework revolves around three dimensions: (1) competence in one's knowledge, (2) performance and engagement in STEM practices, and (3) recognition by others in the STEM community (Carlone & Johnson, 2007; Stewart, 2022). It has been shown in previous research that STEM identities may be shaped by social situations involving gender and ethnicity as well as within a classroom setting. As to which of these three points is most important is still under debate. Kim and Sinatra (2018) noted that social interactions and recognition by others is most apparent in science educational settings. Noting that identity is social in nature, students interact with peers, teachers, professors, and material in those settings. STEM identity therefore is a highly complex, multi-layered theory that calls for more research.

Self-efficacy is the belief a student has in themselves to successfully complete a task successfully (Bandura, 1977). That is, students who believe they can do well in formative or summative assessments in chemistry are regarded as having high self-efficacy. Self-concept is based on past achievements and how that knowledge influences future achievement. The distinguishing factor is that self-concept relies on past experience, and self-efficacy is future-oriented self-predictions (Bandura, 1977; Gibbons & Raker, 2019). Both have been shown previously in research to support an increase in achievement (Bong, 1998; Marsh, 1990; Shavelson et al., 1976).

Bandura's study set out to understand human behavior and therapeutic procedures rather than learning (Cheung, 2014). This theory implied that self-efficacy, the level and strength of, can be changed by psychological means. Bandura, in 1977, proposed that students gain self-efficacy through four principal sources: performance accomplishments, verbal persuasion, vicarious experiences, and physiological states. The more effective the experience of these sources, the more likely students will increase their self-efficacy. This study generated the framework to aid in the improvement of self-efficacy in teaching-related experiences. Bandura (1997) postulated that students who have personal mastery experiences gain self-efficacy. Successes increase expectations, and efficacy can increase further - failures lower expectations and stunt efficacy. Nevertheless, once a high efficacy is developed in one task, it can, according to Bandura's study, "generalize to other situations in which performance was self-debilitated" (p. 195). The more participant modeling, performance exposure, and self-instructed performance students experience in a course, the more likely they have opportunities to increase their self-efficacy (Gibbons & Raker, 2019).

Currently, there is a paucity of research involving specific self-efficacies and STEM identity of underrepresented groups in chemistry courses. Positive experiences and pedagogical approaches may have an effect on the self-efficacy of students entering general and organic chemistry courses. The understanding of foundational concepts may be linked to the self-efficacy and self-concept of students in higher education chemistry. With the use of qualitative research methodologies, students' positive experiences and enhancement of self-efficacy in higher education chemistry courses can be better understood.

Research Questions

Guided by Social Learning Theory and STEM identity frameworks, the present study investigates perceptions of bonding concepts (VSEPR, VBT, MO theory) among students who successfully completed general chemistry. By foregrounding student narratives, I aim to inform equity-focused curricular design. Based on this background information, I want to pursue the following questions in order to enhance chemistry courses in higher education:

1. How do high-achieving students perceive and emotionally respond to bonding topics (VSEPR, VBT, MO theory) in general chemistry?
2. Which instructional strategies and learning contexts do students describe as most supportive for mastering these topics?
3. In what ways do these experiences influence students' chemistry self-efficacy and STEM identity development?

Author's Positionality

I embarked on this project because of my own experiences in chemistry. As a researcher investigating chemistry efficacy in higher education, I have many life experiences that have shaped my own understanding of what it feels like to be a student taking difficult, systemic courses. With this systemic approach to the curriculum where students are treated differently based on gender, and the environment was extremely competitive, I have been faced with trying to cope and fit in with this field.

For the past thirteen years, I have taught foundational courses such as general and organic chemistry in higher education institutions. Witnessing students struggle with finding the purpose of these courses, my research goals strive to create equitable and positive experiences in chemistry where students thrive not only with the content but with their own self-efficacy and identity to become the humans they want to become.

Method

This project took place solely online due to the current restrictions of the COVID-19 pandemic. Because of the state restrictions for non-essential higher education research, no in-person methodologies were employed. Students who successfully completed general chemistry were invited to join the study via their student email. Participants included 4 students over the age of 18 years who completed the year of general chemistry with a B or better. The participants were attending the same private university for the fall 2020 but enrolled in different organic chemistry sections.

Once consent to participate has been established via a Qualtrics survey, the participants were scheduled to take part in interviews conducted via Zoom. The interviews were audio recorded using an audio recording device. The interview was conducted using a theme-based interview protocol. Conversations between the author and the participants included foundational topics in the general chemistry curriculum that were deemed important for success in future chemistry courses based on current research in chemistry education. These topics had an overarching idea of bonding and the buildup of the molecular view of nature. The dialogue traveled from types of bonding, valence shell electron pair repulsion theory (VSEPR) and valence bond theory (VBT), and molecular orbital theory (MO). After the interviews, audio recordings were transcribed and coded using grounded theory to identify emerging themes.

Participants

Participants were recruited using purposeful sampling methods. The sophomore level students attended the same private university and were taking organic chemistry for the first time in different course sections. Participants had also attended different high schools across the United States and Mary was the only participant to have attended community college for general chemistry. Mary and Susan aspire to become pharmacists, Anna is working towards becoming a nurse, and Howard has hopes of entering the biomedical field. All participants assigned themselves their own pseudonym.

Mary is a Caucasian female. Both of Mary's parents are pharmacists, which formed her aspirations to be a pharmacist as well. Mary identified that chemistry and all STEM subjects were regularly discussed at the table. Her parents have a positive outlook on STEM education which Mary attributed to shaping her view of science. Within Mary's family, education is defined as a necessity. Getting good grades was something Mary remembered was expected. Mary attended a charter high school and during that time took community college courses as well which is when she took General chemistry.

Anna is a Caucasian female. Anna wishes to be a nurse and has been working towards that goal for a few years. Anna's mom has a disability which has affected not only her mom's ability to walk but also affects her family dynamic. Anna has experienced moving around the country to address her mom's care. She values the nurses that have helped her mom and wants to be a nurse to help other people and make a difference. Motivation comes when she sees her mom.

Howard is a Caucasian male. He aspires to enter the biomedical field specifically in research and design. Howard views his parents as always being supportive but not scientists themselves. Howard enjoys watching YouTube to expand his knowledge and find motivation to learn more. Howard identified his enthusiasm for communication aids in his learning.

Susan is an Asian female. Susan wants to become a pharmacist. Susan echoed at a level parental involvement was high in her educational experience. Her parents expected her to get good grades, yet they were always supportive. Susan has found science classes to be approachable since high school, but she has had to study in order to get the grades expected.

Data Collection and Analysis

The data collection was conducted via Zoom, recorded for audio only. Each participant partook in one 90-minute interview. The audio was transcribed by the author and axial coding was completed (Saldana, 2016).

Credibility and Ethics

The participants were able to discuss with the author their perceptions on the data results. During this time, themes were presented to each of the participants in a subsequent Zoom session (not recorded). The participants were able to review the themes presented in their own interviews and comment or change the author's interpretation. No data or themes were changed in these discussions. Although coding of the data was conducted by the sole author to this paper, the participant review was highly desired to allow for reliability and validity. Project was covered by the IRB (Chapman University, IRB-21-24).

Findings

The following section provides insight to the themes that emerged from the axial coding of the four participants' interview transcripts. The three themes presented: Positive experiences lead to engagement, independence as a way to boost confidence, and strategies that were most helpful to the students.

Themes Presented

Theme #1 – Positive Experiences Lead to Engagement

Family Support

It was clear to Mary that her parents loved chemistry when they were in school and still did in their careers. She recalled chemistry as "one of like the main subjects that are like favorites in the family so I've always heard like good things about chemistry and how like my parents really loved it and so I was like, okay, so I'm gonna love it too." Mary identified that most fellow students didn't identify the same way. "And I remember like thinking to myself the first day of class like why like everyone else is freaking out. I should probably freak out too because like I'm sure like they're not all wrong about their feelings." Mary also felt the impact of her fellow classmates with this perception, "I realized who should support be best was my parents because they were more positive ya know."

Howard lived at home during general chemistry but moved on campus shortly after. He recalled talking to his family about chemistry, "they didn't always know what I was saying, but they would listen." He recognized their enthusiasm boosted him. Especially in regard to YouTube channels relating to chemistry, "I would watch them sometimes with my parents. Cuz like they are cool. My parents wanted to be involved."

Anna remembered anxiety towards chemistry courses. "I was definitely nervous for sure like I was I was telling my family like I'm having nightmares about organic chemistry that hasn't even started yet." Anna emphasized that her family created a support system for her to keep perspective and positivity by focusing on confidence. "I think that I just need to like be more confident myself because there really is no there was no reason for me to be to be nervous, it's just like all of the stigma that I've heard about the course that caused me to feel like I couldn't like achieve."

Susan felt her parents focused on grades more, "my parents wanted me to get good grades. So it wasn't enthusiasm but I know I made them proud when I did do well." Her family involvement was discussion based at home as Susan lived at home.

Strong Mothers

Support from strong mothers were presented in all the participants. Each spoke of their education independence with the perception that their mothers held control of the educational journeys until high school. Although from different cultures and backgrounds, each participant identified how their mother provided support that motivated them to succeed. "My mom didn't feel like she really needed to be on my back or ask me anymore it was more of like I want to do this" (Mary).

Howard's mom would regularly check in on him in "a caring sort of way. I felt she really liked hearing what I was doing and give her 'mom' love." Howard explained he and his mom were close when it comes to school. She would enjoy talking to him about his day and would ask questions regularly. He explained this made him feel that his mom wanted to be present for him and support his academic identity.

Susan looked to her mom for support. "My mom wasn't in a science field for work, but she would help me by studying with me. Flash cards and stuff like that mostly." Susan would regularly try to explain topics in chemistry to her mom just to check her own understanding. This was portrayed as a metacognitive approach to studying.

High School Influence

Positive experiences from high school chemistry emerged in participants. Howard specifically remembered his poor performance vividly. "I was able to take three years of chemistry in high school, um because I got determined to be bad at science, so they put me in in a slower-paced chem course. At the end of it, I refuse to believe that was all that science has ever done in the world." It was this perseverance that made him successful ultimately. Howard turned a negative experience into a positive one by going outside of the classroom. This was encouraged by his teacher. This will also be discussed further in regard to self-motivation.

Mary noted her motivations changed in high school. "Once I reached high school my mom said that I had my own motivations to get my stuff done. Like I was really into college classes from 9th grade." She had fun in high school science classes, especially chemistry. This motivation continued to higher education.

Anna enjoyed chemistry and remembered the teacher and experiments vividly. "I can't always know what the point was, but I remember my high school chem teacher doing experiments and doing a bunch of hands-on stuff." Recalling different flame colors was Anna's favorite memory.

Theme #2 - Independence as a way to boost confidence

When to Rely on Community vs Individual Learning

Priority was given to creating study groups or communities outside the classroom but was not always their best mode of studying. Anna noted, "we'd give each other like random compounds and say "hey, oh draw it right now! Which was good to study, but sometimes I just started by myself studying first." This was echoed in Susan's experience of group study sessions. "I used to go, but then like sometimes I felt like they were like mistakes that were kind of confusing me, so I stopped going to those and just started doing more practice problems on my own”

Howard noted specifically a timeline that led him to effective studying, “I would start with a group, we would do the quizzing of each other but then a day or two before the exam, I would be on my own.” The group identity was helpful to “initiate studying” for Howard but to get deeper knowledge, he would “get lost in it myself.” Each participant had a group to study with, however, their reliance on that group varied. Overall, each participant identified when the group was helpful and acknowledged there were times when independence was more effective.

Self-motivation

Self-motivation emerged from Anna early in the interview. “I'm also motivated because my mom can't walk so I don't I think of it as I want to do what she can't do, you know what I mean, so. My mom was always needing to be taken care of. So, I didn’t want to be like another you know problem. So, I'm always like on top of my thing but that's just me.” When reflecting on the conversion to online learning Anna found, “Looking back I always evaluate myself based on others, so I think also going online that kind of helped me personally because um, I couldn't see that like how others were like responding to the to the curriculum and that made me feel like more independent and like I wanted to do this for myself not based off others, so I think that was like an interesting thing, how was teaching online versus in person.” Anna realized that her motivation to self-regulate came from her classroom experience and her home life.

Susan identified her motivation came from wanting to get into pharmacy school. “I have wanted to get to grad school which I know is difficult. I need to be on top of my work right from the beginning.” Susan said she rarely watched other students and their performances. “I wanna do it for myself; I think, well, that makes me the most happy.” Susan’s self-motivation is more intrinsically based.

Howard also felt this self-motivation in high school. As previously quoted, Howard wanted to know more because of his initial limited view of chemistry. He recalled that because his teachers didn’t expect much from him, he wanted to prove it to himself that he could know more. Howard spoke of this throughout the interview, “I just wanted to show it to myself […] I am more that what they thought and I didn’t care if they knew it, I knew it.” His motivation was not for praise from teachers, he had a drive to learn for himself.

Metacognition

Mary noted the ability to self-regulate allowed for balance between community “I think I'm more of an independent [learner] like it's just gonna be become a distraction for me yeah if I have other people around.” Mary knew studying with her friends was helpful and when it was not. She also identified self-regulation tools through experiences and teachers. “My general chemistry teacher taught me to set goals. Realistic goals. They would have us write them down and stuff each week.” Metacognition wasn’t the word used but all the participants identified some sort of goal setting within or outside of class.

Anna would make lists, “I made them for myself so that I could organize my time. I wasn’t great at that in high school but with my mom, I needed to be.” Anna was creating goals for herself to identify what she knew and what she needed to study. Overall, she reflected that the list of what she knew kept her positive in continuing, “As the list got longer, I was proud of myself.”

STEM Identity

During the interviews, STEM identity was approached only as it applied to their sense of community and belonging in their chosen fields. Howard loved talking about chemistry to others, “I would regularly talk about these topics [MO, VBT, and VSEPR theories] with other people: classmates, professors, anyone!” He identified the social interactions helped him the most when it came to belonging within a group.

Anna didn’t find that belonging on campus. “I would talk to my mom’s nurses and watch what they were doing. Yeah, I knew I could do it because I would talk to them and see them." Her STEM identity seemed strengthen by social interactions but some of them without words, "I saw nurses that matched me – my hair, my face, my identity. I could see myself becoming them. Even if we didn't talk much, I knew I could do the same – help people and families."

Mary attributed her parents to her STEM identity. "I knew what my parents went through to become pharmacists and so I know it may be hard, but I can do it too."

Theme #3 - Helpful instruction strategies

Visuals

Anna relied on powerful visuals in textbooks and lectures. "I remember the colors and each other of the little atoms and what order they go in so it's I guess I memorized the chart but like the visual was super helpful." Anna spoke vividly on how looking at the pictures rather than reading the words is how she experienced the textbook primarily. Susan echoed this by identifying she rarely read the textbook and often found images online to help her.

Another visual that was helpful for Howard was molecular model kits that was brought into class during the first semester general chemistry course. "Those are super helpful because trying to understand these weird shapes that people named but then seeing the three-dimensional shape super great." The pictures in the book when discussing VSEPR theory weren't helpful for Howard. He struggled in class and with readings, however, when the model kits came out, "it just clicked. Like the shape was right there and I would just rotate it in my hands. The visual was perfect." When it was time for MO theory, Howard was more lost, "I couldn't get a good visual until I found some YouTube videos. They were better than the textbook for sure."

MO Theory, VBT, and VSEPR were all topics that created roadblocks for the participants. They identified the need for visuals, however, from different sources: textbooks, professors, or social media. The visuals helped with anxiety when trying to read the words in the textbook or lecture slides for all four participants.

In Depth Explanations Aid in Deepening Understanding

Detailed lectures provided motivation for Howard in high school and again in higher education. "An eye-opening sort of moment because she explained [ionic and covalent bonding] to us in so much more detailed and I just remember having like half a page for covalent, ionic, and all these bonding types. I didn't use it because that wasn't on the exam because that would be crazy, but I mean nevertheless it was still like very helpful to understand." Howard would constantly ask the professor for more information on VBT and MO theory. "When they didn't want to take the time for more explanations, either in class or office hours, I went to the internet." The desire to learn more about a topic helped Howard "wrap [his] head around it."

Susan repeated the desire for depth in content as well. "Metaphors make it more complicated. Just in general like if it's a simple concept, the metaphors complicate things and then like I'll have to like to reiterate my question. I wish it was just more in depth rather than trying to simplify it." Susan would often go to other people: professors, other students but not the internet. She felt more comfortable talking to other people rather than using videos or reading.

Application Problem Solving

Each participant noted that their chemistry courses in some degree used problem solving strategies to organize. Mary specifically noted that this organization only worked sometimes. "You gotta like actually consider everything else even though it's not one of your steps formally." Mary also identified that real life applications of these problems were challenging.

Outside in his personal life, Howard watches science YouTube channels. “Then I watch a lot of very very small youtubers like under 3,000 subscribers and they all do lasers and I'm super interested in lasers. There's this guy named Styropiro; he's a chemist but he plays with lasers. He made a Tesla coil that puts out so much energy.” This way of seeing how chemistry topics affect the real world helped Howard. “I could see it affecting my life. Which is super cool.”

Table 1
Summary of Word Choices Related to Themes Presented

Theme	Words and Phrases	Count/N	
		Male (N=1)	Female (N=3)
Positive Experiences Lead to Engagement	Parents, Mom, Mother	8	10
	Fear, Afraid, Scared	5	9
Independence as a way to boost confidence	Myself, On My Own	9	3
	Study Group, Study Sessions	4	7
	Goals, Lists	3	4
Helpful instruction strategies	Visuals	4	3
	Explain, Explanations	4	2
	Applied, Applications	2	5

The count of word choices was utilized to identify if any differences in male/female participants could be identified. From Table I, it can be shown that all participants discussed the first and last theme evenly. Howard identified words such as “myself” and “on my own” more often than Susan, Mary or Anna. However, the female participants did use words revolving group sessions more often.

Results and Discussion

This study set out to understand how successful students experience foundational bonding concepts and how these experiences relate to identity and efficacy. Consistent with Bandura’s theory, mastery experiences and social persuasion emerged as pivotal. All four participants attributed confidence gains to either supportive instructors or autonomous problem-solving, echoing findings by Bettinger et al. (2021) and Pawlak & Barbera (2024).

Positive experiences touched on the participants lives in many different ways. The positive experience in each, however, led to more positive experiences. As Mary experienced, her positive outlook on chemistry as provided by her family may have been distressed by observing fellow students who carried negative feelings. This identifies the malleability of self-efficacy. Mary’s family support and past knowledge allowed for the strengthening of her positive experiences. Participants each mentioned their family involvement within their educational experience that led to positive outlooks on their chemistry courses. Anna did not enter chemistry courses with the same positive outlook. Instead, she was extremely fearful and had nightmares. Even with these anxieties, her family unit did enhance and stabilize her experiences in chemistry. Specifically, family support through the strong mother figure emerged within this study. Participants focused their narratives on their mothers more often and in positive perspectives. These positive experiences all led to a future positive outlook which allowed the participants to continue in their chemistry courses. These narratives resonate with research showing that schools and families operate as intertwined enculturation systems—schools as frequent catalysts and families as protectors of values that sustain motivation and belonging (Dogutas, 2020).

High school certainly was a moment for independence. These students each took hold of their motivations and independence in high school. Interestingly, motivation came from both positive and negative experiences. Metacognition and self-regulation were themes presented here. Understanding when to study in groups was valued. Community learning is appreciated but not utilized as much as independent learning. Mastery experiences and social persuasion are two of the four constructs in Bandura's SLT7. When discussing their ability to regulate their own studying, the participants connected their success to metacognition.

Self-efficacy has been linked to grade outcomes and motivation (Ainscough et al., 2016; Galyon et al., 2011). Yet, it would be interesting to see how alternative pedagogies could play a role in the enhancement of student self-efficacy. Numerous studies have noted positive outcomes with the use of critical pedagogy and culturally relevant pedagogy in a variety of different higher education subjects (Kokka, 2018). Unfortunately, the only thing that has been done to this point in chemistry education is changes to the curriculum delivery – flip style or active learning modalities are both hot topics – have focused on grade outcomes and not self-efficacy. Participants presented they valued real-life practice problems. This can be found in new pedagogical approaches such as critical and cultural relevant pedagogies. These are not widely used in STEM fields but could provide new insight to self-efficacy enhancement.

With helpful instruction strategies, Anna noted the use of color, Mary desired words to understand concepts and Howard and Susan focused on in depth discussions. This division shows there should be diversity in methodologies employed in higher education. Currently, much of the curriculum for chemistry in higher education is focused on written assessments and is content-heavy. Instituting a Universal Design for Learning (UDL) approach may be helpful. The overall idea of UDL is to create environments and curriculum that is accessible equitably by all students (Fovet et al., 2010). The tenets of UDL include providing an educational experience that has multiple means of representation, action and expression, and engagement (Meyer et al., 2014). UDL is starting to be identified in higher education STEM but deserves more attention (Basham & Marino, 2013; Moon et al., 2011). This provides new areas of research again into alternate pedagogical practices.

Each participant identified that they wanted to be a part of the scientific community. They had different views of where they were on that journey, however, each had a strong STEM identity of where they wanted to end up. Of the three dimensions of STEM identity, Howard excelled in competence and performance but rarely looked for recognition or validation. The female participants often focused on recognition from classmates or professors to enhance their self-efficacy. These participants had fostered their STEM identity growth through different modalities. They didn't identify the classroom itself as one of those places of belonging. Rather, they found belonging outside the classroom through social interactions – both verbal and silent.

Gendered patterns in language and learning preferences Table 1 indicated that female participants mentioned collaborative "study sessions" more often, whereas the male participant referenced independent study. This aligns with Kim et al.'s (2023) survey of 312 chemistry students, which reported that women were more likely to value peer-instruction spaces. Our data suggests that recognizing these preferences could inform targeted study-support structures.

Now, more than ever before due to the societal inequities in our world, higher education chemistry is faced with an important task. I identify these implications for practice:

1. Embed multiple visualization modalities (physical models, interactive simulations) to support spatial reasoning.
2. Integrate structured collaboration - opt-in peer-learning groups that respect differing autonomy preferences.
3. Adopt UDL principles by offering flexible, mastery-oriented assessments.
4. Provide early metacognitive training, including goal-setting and self-assessment checklists.

Limitations

As with most qualitative approaches, caution should be taken in generalize the results of this project. The number of participants is small and therefore extrapolations to larger populations should be limited. Secondly, the students' narratives are a small illustration of their larger experiences, and those descriptions could change as they continue their academic paths. Finally, the purposeful sampling employed in this study identified four students attending the same private university. The student perspectives are limited to their experiences in this higher education setting as well as their own personal high school experiences.

Beyond the small, single-institution sample, the fully online COVID-19 context likely shaped participants' experiences (Hall & Shaw, 2022). Findings may not transfer to traditional in-person laboratories. Future work should replicate the study with larger, more diverse cohorts and mixed-methods designs.

Conclusions

Due to the paucity of research on the topic of higher education chemistry and the role of student experiences, the following areas of future research may provide a greater understanding of the role of self-efficacy in education on student engagement. The diversity of the U.S. Education system within the past 50 years has created an opportunity for educators to diverse their own pedagogical approaches. It is now time for higher education chemistry professors to expand their classrooms to have equity: a chance for every student to embrace their identity and succeed. Chemistry educators should strive to continue to be effective through embracing new modes of student engagement and enhancing their pedagogy to increase student self-efficacy. This call is echoed in our current state of post-pandemic learning.

Taken together, recent qualitative studies converge on actionable levers for persistence: build intentional cohorting and mentoring in online programs (Akojie et al., 2019); professionalize academic advising with structured preparation (Houdyshell & Kirk, 2018); redesign policies with equity in mind, including workload and evaluation expectations that account for gendered care labor (Platt et al., 2022); and recognize enculturation processes that shape how learners and families perceive schooling (Dogutas, 2020). These levers imply that student success emerges from aligned structures, not isolated interventions. COVID-era learning intersected with home responsibilities; qualitative work with motherscholars documents how intensified gendered care roles can shape persistence and well-being, suggesting the need to interpret online-only findings in light of domestic contexts (Platt et al., 2022).

Revisiting our opening claim that positive, identity-affirming chemistry experiences can mitigate attrition, the present findings demonstrate that strategic independence, authentic visuals, and socio-emotional support collectively nurture self-efficacy. Educators should consider equity-centered design that leverages these levers to broaden participation in chemistry. Institutions should formalize supports (advising responsiveness benchmarks, cohort-based peer communities, embedded writing/library help) that align with UDL's multiple means of engagement and regulation.

Funding Details

This work was not supported by any grant funding.

Disclosure Statement

There is no benefit or financial interest that arose from this research.

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