

Article

Factors Influencing Students' Academic Success in Introductory Chemistry: A Systematic Literature Review

Jessica Chestnut and Carla C. Johnson * 

Department of STEM Education, North Carolina State University, Raleigh, NC 27695, USA; jnchestn@ncsu.edu

* Correspondence: carlacjohnson@ncsu.edu

Abstract: Undergraduate introductory chemistry is a gatekeeping course preventing students from persisting in STEM degree programs. It is important to understand students' experiences of introductory chemistry and better support students as this course traditionally has high attrition and failure rates. This systematic literature review examines the factors of academic success for undergraduates in introductory chemistry courses and aims to understand how these factors differ for varying student groups. A meta-analysis of 35 articles uncovered three emergent themes for promoting students' academic success: course design, instructional tools and resources, and student learning and characteristics. Most notably, active learning environments, metacognitive assessments, and student affective variables such as identity and motivation emerged as significant predictors of students' academic success. Additionally, this review demonstrates how differences in student demographics, achievement levels, affective variables, and participation in chemistry affect the extent to which students succeed in this course. Student demographics were most frequently reported to cause disparities in course performance, with students from historically underrepresented populations exhibiting the most disadvantages in overall course performance. These findings signify the importance of creating effective learning environments in introductory chemistry for students from diverse backgrounds to achieve equitable outcomes and sustain STEM interest.



Academic Editors: Jack F. Eichler and Oluwatobi Odeleye

Received: 24 January 2025

Revised: 15 March 2025

Accepted: 20 March 2025

Published: 25 March 2025

Citation: Chestnut, J., & Johnson, C. C. (2025). Factors Influencing Students' Academic Success in Introductory Chemistry: A Systematic Literature Review. *Education Sciences*, 15(4), 413. <https://doi.org/10.3390/educsci15040413>

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Keywords: chemistry; learning; teaching; retention; achievement; confidence

1. Introduction

The capacity to meet growing economic and workforce demands relies on the retention and completion rates within Science, Technology, Engineering, and Mathematics (STEM) undergraduate degree programs. A report by the [President's Council of Advisors on Science and Technology \(2012\)](#) projected a shortage of one million STEM graduates over the decade spanning 2012 to 2022. The demand for skilled professionals in STEM fields is on an upward trajectory, with the [U.S. Bureau of Labor Statistics \(2020\)](#) projecting continued faster growth for STEM employment compared to non-STEM employers. Another study by the U.S. Bureau of Statistics in ([Fayer et al., 2017](#)) reported roughly 8.6 million STEM jobs available in life science, mathematics, computer science, physical science, and engineering. This report also projected STEM employment will increase by 8.8% between 2018 and 2028 in the United States, with computer science occupations showing the largest growth ([U.S. Bureau of Labor Statistics, 2020](#)). There is a critical need for educational institutions to not only increase the number of graduates in STEM fields but also to ensure their readiness for the workforce.

Despite growing workforce demands for STEM professionals, approximately 40% of students who embark on a STEM major actually persist to their graduation (Chen, 2013; President's Council of Advisors on Science & Technology, 2012). STEM retention in 2013 was reported at a national average of 48%, with community colleges only reporting 30% retention for their STEM majors (Chen, 2013). Attrition rates for STEM majors have also been observed to be much higher than attrition rates of non-STEM majors. The perceived difficulty of STEM programs has been noted as a concern that diverts students from potential STEM degree programs and STEM careers. While many students will express interest in STEM fields as high school seniors, only 21% of high school graduates are academically underprepared for the coursework required in introductory STEM courses (ACT, 2018). Long-term retention and graduation of STEM undergraduates has been previously "predicted significantly by cumulative grade point average, financial need, aid (work-study, loan, and gift), gender, ethnicity, years living on campus, high school rank (HSR), ACT composite, out-of-state residence, and STEM status" (Whalen & Shelley, 2010, p. 45). When controlling for financial variables, Whalen and Shelley (2010) observed students from historically underrepresented populations to be significantly less likely to be retained in STEM fields or graduate within six years when compared to well-represented populations.

The disparities in retention and completion rates among different demographic groups adds an additional layer of complexity to persistence in STEM undergraduate degree programs. While retention rates for White, Asian, and male students in STEM are relatively higher, historically underrepresented gender and racial minorities exhibit markedly lower completion rates. Figueroa et al. (2017) found that only 25% of African American, Latino, and Native American students complete a STEM degree within six years, compared to 44.5% of their White and Asian counterparts. Another study found that degree completion rates are roughly half that of the national average for students from underrepresented racial and ethnic minorities. Disparities among gender are also observed in the retention and persistence of STEM graduates. Chen (2013) found that 43% of female community college students switched out of STEM majors while only 29% of their male peers left. Female STEM undergraduates are frequently underrepresented in STEM fields and achievement gaps have been observed to favor male students (Chen, 2013; Figueroa et al., 2017; Whalen & Shelley, 2010). Given the disparities in STEM that exist for students from traditionally underrepresented populations, research efforts should be focused on retaining a diverse group of students and reducing achievement gaps.

Significance of Introductory Chemistry

Several of the STEM degree programs with high rates of attrition see dropouts occurring within the first year of taking introductory coursework (Figueroa et al., 2017; Freeman et al., 2014; Seymour & Hewitt, 2000; Stone et al., 2018). In demand STEM programs such as engineering, computer science, and healthcare fields, all require introductory courses for undergraduates to pass before they can begin their major specific course content. Chemistry is often hailed as the "central science" given its foundational concepts on the structure of matter and interdisciplinary applications to many STEM degree programs (Tai et al., 2005). Introductory chemistry courses are a prerequisite for several STEM majors and are often considered a gateway, weed-out, or killer course for students (Bressoud, 2020; Lloyd & Eckhardt, 2010; Tai et al., 2005). Undergraduates cannot continue in their intended STEM major if they do not successfully pass their introductory coursework. Many students enrolled in introductory chemistry courses do not intend on majoring in chemistry or biochemistry fields (Gillespie, 1991), which poses an additional challenge to cater to a large audience of STEM undergraduates.

A comprehensive meta-analysis by [Freeman et al. \(2014\)](#) reported an average failure rate of 33.4% for undergraduate STEM introductory courses. When looking specifically at introductory chemistry, institutions have reported failure rates exceeding 50% ([Chambers & Blake, 2008](#)). Academic success in introductory chemistry courses has lasting impacts on STEM persistence and student graduation rates. A study of community college chemistry students found that 32% of students received a D, F, or W in the course ([Cohen & Kelly, 2019](#)). This study further reports that 49% of the students failing chemistry changed their majors and 80% of those majors were changed to a non-STEM field. An analysis by [Stone et al. \(2018\)](#) revealed a direct correlation between grades in first-semester general chemistry and overall graduation rates. Students who achieved passing grades in introductory chemistry had a 73% graduation rate while those that failed the course had a 43% graduation rate. Only 14% of the students failing the chemistry course changed their majors to non-STEM fields and eventually graduated ([Stone et al., 2018](#)). Given these insights, it is evident that introductory chemistry courses are integral to the future of STEM education and workforce development. Prior studies seeking to understand academic success for students in introductory chemistry courses have revealed that student-centered learning, alternative assessments, student agency, and identity-based interventions help increase academic performance and persistence in STEM programs ([Bressoud, 2020](#); [Chen, 2013](#); [Freeman et al., 2014](#); [Stone et al., 2018](#); [Ryoo & Winkelmann, 2021](#)). It is important that students in post-secondary STEM coursework are engaged in active learning, as defined by [Hartikanean et al. \(2019\)](#) as “student-centered and activating instructional methods and instructor-led activities” as opposed to more “traditional, content-centered approaches, such as lecturing”. Addressing the challenges within chemistry introductory courses through innovative teaching methods, supportive learning environments, and consideration of demographic influences is crucial for fostering success among a diverse student population.

This systematic literature review (SLR) examined the empirical research base regarding delivery of the introductory chemistry at higher education institutions and associated student academic success in this gateway course. The goal of this study was to examine research published over the most recent decade (2014–2023) and to generate a comprehensive list of factors which facilitate academic success for students from various ethnic/racial, gender, and socio-economic backgrounds in introductory chemistry coursework. [York et al. \(2015\)](#) has created a theoretical framework of academic success that comprises “academic achievement; acquisition of knowledge, skills, and competencies; and persistence and retention” (p. 2). For the purposes of this SLR, academic success will use traditional measures based on the students’ academic performance and defined as passing the first semester general or introductory chemistry course with at least a 70% (C or higher) grade. As prior literature has shown, gateway introductory courses play a significant role in the academic journey of students, and introductory chemistry, in particular, has suffered from high rates of attrition ([Chambers & Blake, 2008](#); [Figueroa et al., 2017](#); [Stone et al., 2018](#)). The rationale for this research is grounded in the position that undergraduate introductory chemistry is required for many STEM-related degree programs, thus, it is critical to better understand how to support students well so that they complete the course and move forward in their programs.

This systematic literature review was focused on addressing the following questions: (1) What factors contribute to undergraduate students’ academic success in introductory chemistry courses, and (2) How does success in undergraduate introductory chemistry differ based on student background?

2. Materials and Methods

2.1. Database Search and Article Selection

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021) guided to this SLR which focused on analyzing the factors of academic success for undergraduates in introductory chemistry. The purpose of this study was to determine how this field of inquiry had evolved over the most recent decade (2014–2023). The initial search for articles was conducted with multiple databases (ERIC, Academic Search Complete, Google Scholar, and Proquest); however, due to significant overlap in articles found, the authors decided to include the use of Academic Search Complete (ACS) and Educational Resources Information Center (ERIC). ACS was chosen for its multidisciplinary applications in higher education contexts and provides full-text literature for over 9000 journals (NC State University Libraries, 2024). ERIC was also selected as it serves as the primary database in education research contexts. The ERIC database covers a range of educational institutions and contains over 750 journals (NC State University Libraries, 2024). Both ACS and ERIC databases produced articles based on the following Boolean search term: introductory chemistry AND undergraduate AND (success OR achievement OR performance). Research studies were limited to full-text articles in scholarly, peer reviewed journals written only in English over the past nine full years (2014 to 2023). The ACS database produced 57 articles, and the ERIC database produced 77 articles. These results were exported as a CSV file and imported into Excel to undergo further screening of selection criteria.

2.2. Screening and Excluded Studies

PRISMA guidelines were utilized for identifying and screening research studies to be used in this SLR (Page et al., 2021). Figure 1 summarizes the process for identifying research articles from the ACS and ERIC databases, screening of the abstracts and full-text articles, and exclusion criteria to finalize the 35 studies to be included in this SLR. Of the articles produced from the initial ACS ($n = 57$) and ERIC ($n = 77$) database searches, seven duplicate articles were removed resulting in 127 articles subject for abstract screening. These abstracts were screened to ensure they were relevant to the guiding research questions of this SLR study. Articles were excluded from the study based on the following criteria: (1) articles not focused on undergraduate introductory chemistry, (2) articles which include discipline specific courses like organic chemistry, biochemistry, or upper-level courses, (3) articles focused on other STEM non-chemistry disciplines, (4) articles not focused on undergraduates in higher education, (5) articles that only discussed the chemistry laboratory and not classroom context, and (6) articles that were not empirical studies or published in peer reviewed scholarly journals. For example, during the abstract screening one research article titled “Using touch-screen technology, apps, and blogs to engage and sustain high school students’ interest in chemistry topics” was rejected for its use in high school contexts and not higher education (Kim et al., 2014). Another research article titled “The roles of motivation and metacognition in producing self-regulated learners of college physical science: a review of empirical studies” was rejected for its use of interdisciplinary STEM fields such as physics (McDowell, 2019). The research article titled “Simple and inexpensive 3D printed filter fluorometer designs: User-friendly instrument models for laboratory learning and outreach activities” was rejected for its laboratory context and use in upper-level courses (Porter et al., 2017). A total of 86 abstracts were rejected during this initial screening process.

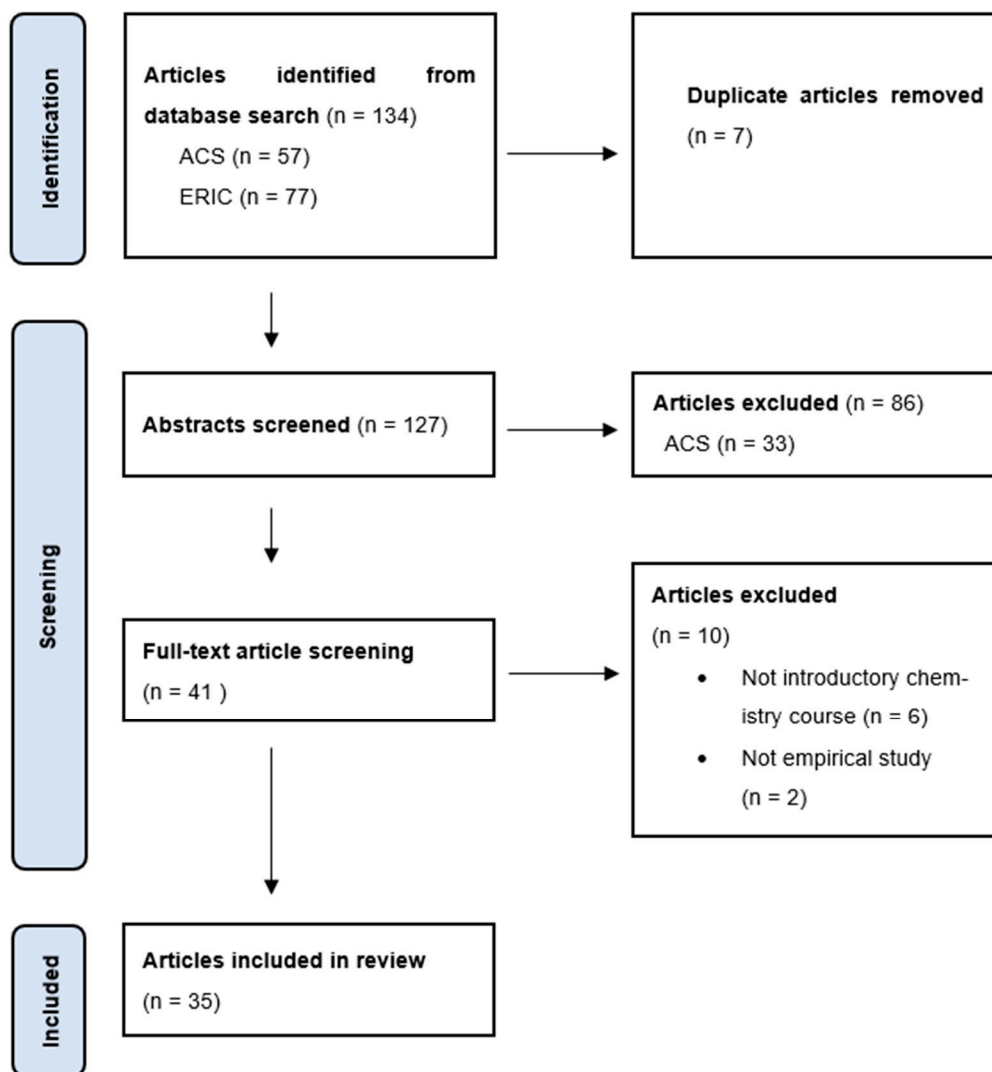


Figure 1. PRISMA Flow Diagram of Review Protocol. Note. Adapted from [Page et al. \(2021\)](#).

Once the abstract screening was complete, a total of 41 articles moved on to the next phase of full-text screening and were downloaded into the reference manager Zotero. Upon full-text reading, ten articles were rejected based on exclusion criteria. Six studies were rejected for focusing on upper-level chemistry courses or other science disciplines. For example, the research article titled “Benefits of a game-based review module in chemistry courses for nonmajors” was rejected due to its focus on a biochemistry course and not an introductory chemistry course ([Stringfield & Kramer, 2014](#)). Two studies were excluded for not being primary and empirical research studies. For instance, the research article titled “Radical awakenings—A new teaching paradigm using social media” was excluded as this was a review of a conference paper and not an empirical study ([Sorensen-Unruh, 2017](#)). Finally, the last two studies were excluded for not focusing on students in introductory chemistry courses and instead focusing on the validation of survey instruments. After the full-text screening process, a total of 35 research articles were included in the study.

2.3. Data Analysis

Rather than using a conceptual framework to structure the coding process, thematic synthesis was used to analyze the articles in this study where themes emerged from the primary studies ([Thomas & Harden, 2008](#)). The three stages of this approach include the following: (1) coding selected text, (2) development of descriptive/emergent themes,

and (3) generation of analytical themes (Thomas & Harden, 2008). First, the 35 research articles included in this study were categorized based on the year of publication, journal, location of the study, and study type based on methodology. Descriptive statistics were also used to quantify these variables. The articles then underwent thematic analysis to understand the factors of academic success for introductory chemistry students and how these factors may differ based on various groups of students. Thematic analysis was guided by the research questions and took an iterative approach to refine inductive codes developed from research article analysis and produce emergent themes (Schreier, 2019). To answer the first research question, commonalities in initial codes were used to categorize factors of academic success. The articles were then analyzed thoroughly a second time to refine the categories and then finalized as analytical themes that were refined to answer the first research question regarding the factors of academic success of undergraduate introductory chemistry students. Thematic analysis was also used to answer the second research question. Studies were categorized to determine how they were investigating various group differences that affect academic success. For each article, findings, discussion, and implications were coded independently by the lead author. The second author on this manuscript independently coded a subset of articles which provided inter-rater reliability for the SLR analysis. Our team independently assessed intercoder reliability (ICR) for each code at the end of each “testing round”. When 80% agreement on 95% of codes (Miles & Huberman, 1994) was achieved, the coding framework was finalized, and coding of remaining data will continue independently.

3. Results

The results of this study are presented through addressing the two research questions. The first research question examines the factors that are associated with student success in introductory chemistry coursework. The second question delves deeper to determine any nuanced differences by student subgroup. Details regarding the 35 articles included are provided in Table 1 such as journal of publication, location of study, and study type based on methodology. The year 2023 was the most common ($n = 7$, 20%) year of publication for articles in this study. Other years of publication included 9% ($n = 3$) of articles in 2014, 9% ($n = 3$) in 2015, 9% ($n = 3$) in 2016, 11% ($n = 4$) in 2017, 9% ($n = 3$) in 2018, 11% ($n = 4$) in 2019, 9% ($n = 3$) in 2020, 9% ($n = 3$) in 2021, and 6% ($n = 2$) in 2022. While the year 2024 was included in the search criteria, the database searches did not produce articles from 2024 since this search was conducted in February 2024.

The most common journal that 46% of studies ($n = 16$) were published in was the Journal of Chemical Education. Other journals that research articles were published in included Psychology of Women Quarterly ($n = 1$), Educational Technology Research and Development ($n = 1$), Journal of Experimental Education ($n = 1$), Educational Psychology ($n = 1$), Computers and Education ($n = 1$), Annals of the New York Academy of Sciences ($n = 1$), School Science and Mathematics ($n = 1$), Journal of Counseling Psychology ($n = 1$), Journal of the Scholarship of Teaching and Learning ($n = 2$), Chemistry Education Research and Practice ($n = 4$), EURASIA Journal of Mathematics, Science and Technology Education ($n = 1$), College Student Journal ($n = 1$), Journal of Science Education and Technology ($n = 1$), Electronic Journal of Science Education ($n = 1$), and Journal of Teaching and Learning with Technology ($n = 1$).

Table 1. Descriptive Overview of Selected Literature.

Article Reference	Journal	Study Location	Study Type
(An et al., 2022)	Journal of Chemical Education	U.S.	Quantitative
(Bergey et al., 2023)	Journal of Experimental Education	U.S.	Mixed Methods
(Bokosmaty et al., 2019)	Journal of Chemical Education	Australia	Mixed Methods
(Brown et al., 2015)	Journal of the Scholarship of Teaching and Learning	U.S.	Quantitative
(Bunce et al., 2017)	Journal of Chemical Education	U.S.	Mixed Methods
(Chan & Bauer, 2014)	Journal of Chemical Education	U.S.	Quantitative
(Carpenter et al., 2020)	Journal of Teaching and Learning with Technology	U.S.	Quantitative
(Clark, 2023)	Journal of Chemical Education	U.S.	Quantitative
(Cosio & Williamson, 2019)	Journal of Science Education and Technology	U.S.	Quantitative
(Cracolice & Busby, 2015)	Journal of Chemical Education	U.S.	Quantitative
(Edwards et al., 2023)	Journal of Chemical Education	U.S.	Quantitative
(Fink et al., 2020)	Chemistry Education Research	U.S.	Quantitative
(French et al., 2023)	Psychology of Women Quarterly	U.S.	Quantitative
(Gilewski et al., 2022)	Chemistry Education Research and Practice	U.S.	Mixed Methods
(Gulacar et al., 2019)	EURASIA Journal of Mathematics, Science and Technology Education	U.S.	Mixed Methods
(Hardin & Longhurst, 2016)	Journal of Counseling Psychology	U.S.	Quantitative
(Hawker et al., 2016)	Journal of Chemical Education	U.S.	Quantitative
(He et al., 2018)	Computers and Education	U.S.	Quantitative
(Kyne et al., 2023)	Chemistry Education Research and Practice	Australia	Mixed Methods
(Msonde & Van Aalst, 2017)	Educational Technology Research and Development	Tanzania	Mixed Methods
(Ott et al., 2018)	Journal of the Scholarship of Teaching and Learning	U.S.	Quantitative
(Perez et al., 2023)	Annals of the New York Academy of Sciences	U.S.	Quantitative
(Philipp et al., 2016)	Electronic Journal of Science Education	U.S.	Quantitative
(Revell, 2014)	Journal of Chemical Education	U.S.	Quantitative
(Smith et al., 2018)	Journal of Chemical Education	U.S.	Quantitative
(Talanquer, 2017)	Journal of Chemical Education	U.S.	Quantitative
(Talanquer & Pollard, 2017)	Journal of Chemical Education	U.S.	Quantitative
(Tang et al., 2014)	Journal of Chemical Education	U.S.	Quantitative
(Tashiro & Talanquer, 2021)	Journal of Chemical Education	U.S.	Quantitative
(Todd et al., 2021)	Chemistry Education Research and Practice	U.S.	Quantitative
(Van Duser et al., 2021)	College Student Journal	U.S.	Quantitative
(Wang et al., 2021)	Educational Psychology	U.S.	Mixed Methods
(Wong et al., 2023)	School Science and Mathematics	U.S.	Mixed Methods
(Ye et al., 2015)	Journal of Chemical Education	U.S.	Quantitative

Quantitative methodology was the most common method used by researchers as 71% of studies ($n = 26$) used quantitative analysis to understand factors of academic success for introductory chemistry undergraduates. The type of quantitative analysis varied and included methods such as surveys and descriptive statistics (Hardin & Longhurst, 2016; Revell, 2014; Ye et al., 2015), ANOVA or MANCOVA (French et al., 2023; Todd et al., 2021; Wang et al., 2021), linear or logistic regression analysis (Carpenter et al., 2020; Philipp et al., 2016; Van Duser et al., 2021), cluster analysis (Brown et al., 2015; Chan & Bauer, 2014), latent profile analysis (Perez et al., 2023), Wilcoxon sum-rank tests (An et al., 2022; Bancroft et al., 2020; Smith et al., 2018), chi squared tests (Cosio & Williamson, 2019; Talanquer & Pollard, 2017), and Mann–Whitney U tests (Hawker et al., 2016; Tang et al., 2014). The use of surveys to quantify factors or student characteristics was the most common method, with 58% ($n = 18$) of research studies using surveys and descriptive statistics.

Only nine studies (26%) used a mixed methods approach, and their quantitative methods were similar to the studies listed above. The qualitative methods used in the mixed methods studies included content analysis of a survey with open ended items (Bokosmaty et al., 2019), thematic analysis of focus groups (Gilewski et al., 2022), a word

association test with open coding and network analysis (Gulacar et al., 2019), thematic analysis of student emails and evaluations of the course (Kyne et al., 2023), content analysis of concept maps (Wang et al., 2021; Wong et al., 2023), content analysis of student generated question logs (Bergey et al., 2023), student interviews and content analysis of discussion forums (Msonde & Van Aalst, 2017), and student interviews (Bunce et al., 2017). Only three studies had qualitative methods that involved direct interaction with students such as focus groups or interviews. No studies were identified that used only qualitative methodology to investigate factors of academic success for introductory chemistry students.

The vast majority (91%) of studies ($n = 32$) were conducted in the United States. Two studies were conducted in Australia and one study was conducted in Tanzania. It was also observed that the studies mostly investigated undergraduate students from four-year public universities. The only differences in institution types that were observed included one institution at a U.S. Naval Academy (Bunce et al., 2017) and one at a predominately Hispanic serving institution (An et al., 2022). Only one research article mentioned that their study was implemented at both a community college and public university (Gilewski et al., 2022).

3.1. Research Question 1: Factors of Student Success for Introductory Chemistry Undergraduates

Research question one explored the factors that influence academic success in undergraduates in introductory chemistry courses. Thematic analysis was used to identify the three emergent themes of course design, instructional tools and resources, and student learning and characteristics and the associated categories (Table 2).

Table 2. Summary of the Three Factors of Academic Success for Introductory Chemistry.

Theme	Category	Article Reference
Course design and learning environment ($n = 18$)	Instructional methods ($n = 5$)	Bancroft et al. (2020); Bokosmaty et al. (2019); Clark (2023); He et al. (2018); Tashiro and Talanquer (2021)
	Curricular redesign ($n = 4$)	Ott et al. (2018); Philipp et al. (2016); Smith et al. (2018); Talanquer and Pollard (2017)
	Assessment reform ($n = 8$)	Gulacar et al. (2019); Gilewski et al. (2022); Talanquer (2017); Tang et al. (2014); Todd et al. (2021); Wang et al. (2021); Wong et al. (2023); Ye et al. (2015)
	Online learning ($n = 1$)	Msonde and Van Aalst (2017)
Course resources and feedback ($n = 5$)	Instructional resource ($n = 3$)	Bunce et al. (2017); Cosio and Williamson (2019); Revell (2014)
	Instructor feedback ($n = 2$)	Carpenter et al. (2020); Kyne et al. (2023)
Student learning and characteristics ($n = 12$)	Student characteristics ($n = 8$)	Brown et al. (2015); Chan and Bauer (2014); Edwards et al. (2023); Fink et al. (2020); French et al. (2023); Hardin and Longhurst (2016); Perez et al. (2023); Van Duser et al. (2021)
	Student learning ($n = 4$)	An et al. (2022); Bergey et al. (2023); Cracolice and Busby (2015); Hawker et al. (2016)

Theme 1: Course Design and Learning Environment

The first emerging theme identified in this SLR was course design. A total of 18 studies (51%) discussed how the design of the chemistry course and learning environment contributed to overall student success in introductory chemistry courses. This theme consisted of two different types of course designs: active learning environments and an online learning environment.

Instructional Methods. A study by Tashiro and Talanquer (2021) compared student outcomes between a traditional, lecture-based chemistry course and a reformed course

incorporating active learning strategies at a large public research university. Using hierarchical linear and logistical modeling, the study analyzes differences in student performance and assesses whether educational reforms help mitigate achievement gaps. Instructors either taught using active learning strategies with in-class clicker questions and collaborative learning activities for students or had a more traditional and lecture-based approach. The reformed course had higher course grade averages compared to the traditional course for all academic index ranges. It was observed that students with lower academic index ranges (lower-performing students) benefited from their participation in the reformed course; however, the final exams are different for the two courses (Tashiro & Talanquer, 2021). In relation to academic success in chemistry courses, the research suggests that structured learning environments, inclusive assessment practices, and balancing exam and coursework weights can significantly impact student achievement.

One of the research studies employed the strategy of a fully flipped instructional model to promote students' academic success in their introductory chemistry course (Bancroft et al., 2020). In the fully flipped model, lectures are prerecorded for students to watch outside of the classroom and in-person time traditionally reserved for lectures are instead used for students to work on problem solving in groups. Students in traditional lecture courses and the non-traditional flipped course had their course performance compared to understand the effects of a flipped instructional model. This study noted that withdrawals and D/F grades were decreased for all groups of students when using a flipped model (Bancroft et al., 2020).

Rather than creating a fully flipped instructional model, two studies only partially flipped their classrooms to investigate the effects on student performance in their chemistry courses (Bokosmaty et al., 2019; He et al., 2018). The partially flipped model still requires students to read materials or watch prerecorded lectures outside of the classroom but will still hold some time in class for lectures. Students are also asked to work on problem sets and engage in discussions in the partially flipped model. He et al. (2018) noted in their study that short-term academic achievement was not significantly affected for student final exam grades in the semester of taking the partially flipped introductory chemistry course, but their subsequent chemistry exam grades improved. This study demonstrated that a partially flipped instructional model had a long-term and not short-term benefit for academic achievement. Additionally, this study found that students in the partially flipped model exhibited higher levels of motivation and positive course perception compared to those in a traditional lecture course (He et al., 2018). An Australian university's implementation of a partially flipped instructional model also reported higher student satisfaction with the quality of teaching and learning resources available (Bokosmaty et al., 2019). As opposed to He et al.'s study, Bokosmaty et al. (2019) demonstrated significant short-term learning gains through improved academic performance in course grades. They also reported higher rates of student retention within the three introductory chemistry course sections the partially flipped model was implemented in.

Clark (2023) also studied reformed course utilizing active learning strategies as compared to traditional lecture-based courses. The researchers analyzed data from approximately 9000 students across multiple semesters, including both in-person and online courses. By using statistical regression analyses and controlling factors such as incoming preparation (measured by ACT scores), the study assessed the impact of teaching practices on achievement gaps. During the in-person courses, the instructor of one reformed course was involved in Modeling Instruction pedagogy and emphasized metacognition throughout the course to help students optimize their learning strategies. The instructor of the second reformed course was influenced by peer instruction pedagogy and uses a flipped classroom (Clark, 2023). Both courses used active learning and student-centered learning

approaches, which significantly reduced the achievement gap for historically underrepresented populations compared to traditional lecture-based courses. In addition to active learning, it was observed that course structure and instructional strategies such as pre-class and post-class assignments, student engagement initiatives, and metacognitive learning interventions contributed to student success in the general chemistry course (Clark, 2023). The emergency switch to online instruction, however, had minimal to no student–student interaction or student-centered teaching and adapted a more didactic approach for the online instructional mode. The study concludes that while active learning is valuable, structured learning experiences outside of class time are equally important for reducing disparities in student performance.

Curricular Redesign. Curricular redesign was the focus of a study based out of the University of Arizona (Talanquer & Pollard, 2017). The chemistry department decided to reform their introductory chemistry course by creating a new curriculum focusing on student-centered approaches. Students engaged in an inquiry-based learning chemistry curriculum with some sections taking place in collaborative learning spaces to promote student interactions. Student performance with the reformed curriculum was seen to significantly increase while the failure rates of the standardized American Chemical Society (ACS) exam decreased from 38.5% to 29.2% (Talanquer & Pollard, 2017). Students that completed the reformed introductory chemistry course also showed improved subsequent organic chemistry course performance with more students receiving A's and a decrease in D and F grades compared to students not previously enrolled in the reformed introductory chemistry course sections. Similarly to the study from Bokosmaty et al. (2019), the student-centered approach from Talanquer and Pollard (2017) demonstrated long-term learning gains. Other active learning strategies included a POGIL model to enhance chemistry students' academic performance. One study using POGIL strategies with student teams working on inquiry problems reported an increase in student academic performance and a decrease in withdrawal rates for the course (Ott et al., 2018). Smith et al. (2018) also used an active learning environment with a POGIL approach in their introductory chemistry course. Since this course typically served students in a nursing major, the POGIL activities had a heavy emphasis on healthcare contexts. Data collected over ten semesters at two universities demonstrated a significant positive increase in students' chemistry self-concept. This result indicated that an active learning environment increased the students' belief in their ability to succeed in the introductory chemistry course due to the POGIL activities (Smith et al., 2018). The incorporation of health-related scenarios in the course increased student engagement, which also resulted in a significant increase in course grades.

Philipp et al. (2016) investigated the use of undergraduate teaching assistants (UTAs) in chemistry recitation sections. The UTAs had previously taken the same chemistry course and were employed due to their success in the course and recommendations from faculty. The recitation sections were student-centered and employed a peer mentoring approach. Other recitation sections were traditionally run by graduate teaching assistants (GTAs). The presence of the UTAs only significantly boosted the final exam scores for students that already had above average college GPA's (Philipp et al., 2016). The study found that UTA recitation sections increased the persistence of students in the next subsequent chemistry course regardless of the students' academic achievement. There were, however, no significant differences found in the final exam scores of students with the UTA-led recitation sections compared to the traditional recitations led by GTAs (Philipp et al., 2016). Overall, the studies using active learning approaches examined in this SLR suggest that active learning environments can improve students' academic performance and contribute to long-term learning gains.

Assessment Reform. Chemistry assessments were the most frequently reported tool revealed in this review of previous research. Eight studies reported that certain types of assessments can promote academic achievement for chemistry undergraduate students. Assessment types varied and included the prediction of wrong answers, measurement of linked concepts, concept maps, complexity of stoichiometry problems, word association tests, and retrieval quizzes. [Talanquer \(2017\)](#) created an assessment that required students to predict the wrong answers that another student may choose if they were only relying on their intuition to answer the question. This assessment intervention aimed to improve the analytical skills of students to help them work through chemical reasoning and become more aware of intuitive traps. [Talanquer \(2017\)](#) found that students did have an increase in their concept inventories and analytical skills, along with an increase in overall academic performance in the course.

Another assessment technique highlighted in this SLR was the measurement of linked concepts to understand how students' link chemistry content to their existing knowledge structures ([Todd et al., 2021](#); [Ye et al., 2015](#)). These assessments were targeted at specific chemistry concepts and were incorporated in homework assignments and in-class exams to understand the conceptual links and misconceptions of chemistry students. Students would use the measurement of linked concept (MLC) assessment to respond true or false to items that would link big picture chemical concepts across a variety of topics. This assessment technique was able to identify the common misconceptions that students held about course content so that instructors could address these in class and improve the learning gains of the students ([Ye et al., 2015](#)). [Gilewski et al. \(2022\)](#) also used an assessment to measure linked concepts in introductory chemistry courses at a public university and community college. The MLC assessments were shown to significantly predict students' final exam scores in introductory chemistry. Additionally, the MLC assessment was paired with a metacognitive exercise where students "needed to look at the learning objectives they missed and write a plan for mastering the missed learning objectives" ([Gilewski et al., 2022](#), p. 878). When paired with the metacognitive exercise, MLC scores significantly improved by 18%; however, this improvement did not translate to a statistically significant increase in final exam performance. [Gilewski et al. \(2022\)](#) also demonstrated that students had more engagement with course material because of the MLC assessment and metacognitive exercise. They reported that 87% of students reported revisiting learning objectives they missed and another 54% formulated plans to address these gaps such as reviewing lecture notes or engaging with more practice problems.

Another common type of assessment identified was the use of concept maps. One instance asked students to use concept maps in a chemistry course for the topic of enthalpy ([Wang et al., 2021](#)). In this study, students either had to write a paragraph about the concept map, fill in concept blanks on a partially completed concept map, or fill in labels on a partially completed concept map ([Wang et al., 2021](#)). It was found that students who were required to translate the concept map into complete sentences had significantly better performance on open-ended exam questions. However, no significant differences existed for multiple choice exam questions based on the different treatments of concept maps ([Wang et al., 2021](#)). It was also observed that students translating the concept map spent more time on this activity than the other concept map activities but spent less time answering posttest questions. This result suggests a more efficient retrieval and application of knowledge ([Wang et al., 2021](#)). Another study utilizing concept map assessments asked students to either fill in a blank concept map or correct an incorrect concept map based on the topic of electrochemistry ([Wong et al., 2023](#)). The concept map treatment reported that students filling in the concept map rather than correcting an incorrect map had better learning outcomes. [Wong et al. \(2023\)](#) further investigated the role of student interest

and showed that higher student interest in the topic of electrochemistry also significantly impacted how well a student performed on the concept map activity and correlated with higher posttest scores as well.

One study used a different type of assessment and looked at complexity factors in stoichiometry problems on formative assessments and assessed what problem factors affected problem-solving success (Tang et al., 2014). The stoichiometry problems were randomly generated and differed in variables such as number format, units given, identity of an element, chemical equation, and substance. This study found that only the complexity for the three variables of number format, units given, and chemical equation significantly affected students' academic performance on problem solving (Tang et al., 2014). The stoichiometry problems were also assessed for their cognitive load based on the complexity of the problem and it was found that problems with higher cognitive loads for students resulted in lower student performance. Additionally, Tang et al. (2014) implemented the use of an eye tracking system which revealed that less successful students spent more time focusing on the problem statement and complex variables than students who performed well on the stoichiometry assessment.

Gulacar et al. (2019) created an assessment focusing on word associations to understand the role of students' knowledge structures when given a chemistry related stimulus word. The knowledge structures generated by students with a higher prior knowledge demonstrated more connections and cohesive structures. This study also noted that while mathematics knowledge was important for success in the chemistry course, mathematical background was not a significant influence on the students' chemistry knowledge structures (Gulacar et al., 2019). Students that had more interconnected knowledge structures with concepts such as energy or forces at the center were also noted to be students with high scores on the chemistry placement exam. The use of post-exam retrieval quizzes was another assessment technique used to understand their effect on student performance over the semester (Todd et al., 2021). This study hypothesized that "individuals who participate more in the retrieval practice quizzing will score higher on the cumulative final exam than individuals who elected not to participate" (Todd et al., 2021). The results from the retrieval quizzes revealed that students completing more than 50% of the quizzes performed significantly better on the cumulative final exam than students that completed less than 50% of the retrieval quizzes. There were no significant differences found between the during-term exam grades, suggesting that the use of retrieval quizzes was an effective assessment rather than reflecting general academic ability (Todd et al., 2021). Regardless of a students' achievement level, the retrieval quizzes provided evidence of a forward testing effect where students were able to retain information over time for the cumulative exam. The assessments observed in this study indicate that linking multiple concepts and using metacognitive strategies to reflect on problem-solving processes can increase student learning outcomes.

Online Learning Environment. In addition to courses designed around active learning environments, online learning was also observed to be an important course design factor that promoted students' academic success. There was only one study (Msonde & Van Aalst, 2017) that used an online learning environment as their research study context. This study investigated the differences between non-interactive learning, medium interactive learning, and high interactive learning in a virtual classroom taking place at a Tanzanian university. Main differences in the learning interactions were centered around the use of discussion boards and forums along with interactive assignments such as listening to scientific podcasts and reflecting on chemical connections through the online learning management system. The high interactive learning model had the most substantial gains in academic performance due to the combined use of discussion forums and podcasts. All

designs were seen to improve with academic performance due to student engagement and interaction with the discussion forums (Msonde & Van Aalst, 2017). This study also found that the students using discussion boards and podcasts exhibited improved learning gains, most notably with higher order thinking skills related to analysis, synthesis, and evaluation of course content. Similarly to the active learning environments, improved learning outcomes were credited to the student-centered approaches such as discussion forums utilized in the online learning environment.

Theme 2: Course Resources and Feedback

The second emergent theme identified from the examination of research articles was instructional tools and resources. This theme included five studies (14%) that examined specific tools or resources that instructors implement in their introductory chemistry classrooms to boost student academic performance. Instructional tools and resources were further categorized into instructional resources and instructor feedback.

Instructional Resources. The second category of instructional resources was identified when studies discussed resources that were implemented into the classroom or made available outside of the classroom for students to engage with in their introductory chemistry course. Some of the resources included technology, study materials, and homework platforms. One such resource was the use of technologies such as a tablet PC, lecture capture software, and online homework in a chemistry course (Revell, 2014). The tablet PC was used during lecture presentations so the instructor could annotate slides in real-time, lecture capture software allowed students to rewatch the lectures at home, and the online homework platform of Sapling Learning was used as opposed to textbook problems with handwritten answers (Revell, 2014). This study did not find that the use of lecture replays was significantly correlated with higher grades in the course. Rather, it seemed that international, English as a Second Language (ESL), and students with already weak academic backgrounds used the lecture replays to help them to complete the course (Revell, 2014). The online homework through Sapling Learning was significantly correlated with academic performance, with students completing most homework assignments achieving higher exam and course grades. Additionally, Revell (2014) found positive student perceptions with the tablet PC being rated highest for enhancing student learning and instructor effectiveness. The online homework was also valued for its learning gains to students due to the instant feedback and multiple attempts allowed from the online platform. The use of all three instructional resources led to a significant improvement in student retention compared to previous semesters, with a 90% completion rate for the semester using the three technologies compared to an average of 71% in prior semesters (Revell, 2014).

Another instructional resource explored was the use of study materials such as lecture notes and prior assessments. Bunce et al. (2017) investigated the use of study resources in an introductory chemistry course at the U.S. Naval Academy, where students have many time constraints outside of the class due to academic and institutional obligations. Study resources utilized by students were observed to vary depending on the type of assessment. For example, students often used their lecture notes to study for instructor-written assessments while prior assessments or review guides were used to study for common exams (Bunce et al., 2017). This study demonstrated that study resources and the study behaviors of students are important to understand so that instructors can better support their learning processes.

The last instructional resource that was discussed included the study of homework completion versus student academic performance in introductory chemistry (Cosio & Williamson, 2019). In this study, students were assessed on their reasoning abilities through the Test of Logical Thinking (TOLT) and short-term learning gains through in-class clicker questions. In general, the students that completed their homework before the next lecture

scored higher on exams compared to students that waited more than four days after lecture to complete their homework. [Cosio and Williamson \(2019\)](#) also found that students with low reasoning abilities based on their TOLT scores did not have a significant relationship to their overall exam score based on when they completed their homework. The completion of the homework also had a more significant correlation to long-term exam performance than the short-term measure of clicker questions ([Cosio & Williamson, 2019](#)). Research studies in this SLR demonstrate that a variety of instructional resources and how students engage with them affect the academic success of introductory chemistry students.

Instructor Feedback. Instructor feedback was found to help improve students' academic success in introductory chemistry is instructor feedback. One study analyzed instructor feedback through personalized emails that instructors sent to students which included evaluations on their course performance and advice on support systems and resources ([Kyne et al., 2023](#)). This study states that "affirmation from the feedback emails students received strengthened their belief in their own capabilities" ([Kyne et al., 2023](#), p. 979). As a result, students that received personalized feedback emails had higher academic performance as compared to semesters when this instructor feedback was not provided. The mean course grades of students receiving the emails had a statistically significant improvement from 59.2% to 63.5% ([Kyne et al., 2023](#)). Additionally, this study showed that 85.3% of students were classified in a "good" grades category and 6.8% in a "poor" grades category with the addition of personalized feedback emails as compared to prior semesters without feedback at 78.5% and 17.9%, respectively ([Kyne et al., 2023](#)). Another form of instructor feedback was provided in [Carpenter et al.'s \(2020\)](#) study of exam wrapper feedback provided through an online learning management system. The online exam wrapper was designed to mimic one-on-one feedback sessions and asked reflective questions about students' exam preparation, study strategies, and areas of difficulty. [Carpenter et al. \(2020\)](#) noted that student completion rates of the optional exam wrappers were low, but for the students that did complete them, there was significant correlation between the use of the exam wrappers and course grades. A metacognitive awareness inventory was also distributed to students and findings show that these scores were positively correlated with students' performance in the course ([Carpenter et al., 2020](#)). Instructor feedback is an important instructional tool that can cause students to reflect on their performance in the course and take corrective actions towards improved academic success.

Theme 3: Student Learning and Characteristics

There were 12 studies (34%) for the theme student learning and characteristics. These studies examined how student-based factors such as their learning approaches and characteristics were important factors for undergraduate academic success in introductory chemistry. Measures of student affective characteristics such as their motivations, identity, and values along with the way students approach learning are significant indicators of how students perform in chemistry courses.

Student Characteristics. Eight studies investigated student characteristics to further understand how they affect academic performance in introductory chemistry courses. One study from [French et al. \(2023\)](#) explored the motivation of undergraduate chemistry students through the application of expectancy-value theory to understand links to their academic performance. Findings revealed that "students who dropped the course had significantly lower initial confidence about performance" compared to students who completed the course ([French et al., 2023](#), p. 306). Final exam scores were also significantly and positively predicted by confidence in a students' performance, interest, utility values, and attainment values. Another study from [Perez et al. \(2023\)](#) utilized expectancy-value theory to understand patterns and outcomes of introductory chemistry undergraduates. Similarly to [French et al.'s \(2023\)](#) study, students with high confidence in their chemistry abilities

and moderate utility and attainment values had higher exam scores. It was also stated that “students with the most adaptive profile of beliefs, according to theory, also had the most success” (Perez et al., 2023, p. 78). The majority of the students in the study held a strong belief in their ability to succeed in science, perceived only moderate costs to participate in science, and overall valued science. Thus, students with this motivation profile were not only seen to have higher exam scores, but also long-term persistence in STEM coursework (Perez et al., 2023).

The study by Edwards et al. (2023) examined the sense of belonging and persistence of students in the second sequence of general chemistry courses. The research examined two dimensions of social belonging where the first dimension referred to students’ feelings of connection to peers, instructors, and the course environment. The other dimension referred to belonging uncertainty, which reflects the students’ doubts about whether they truly belong in the course. It is worth noting that this study took place in the COVID-19 pandemic, so both sequences of general chemistry were taught online. The researchers used survey data and performance metrics to analyze the relationship between students’ social belonging in the first semester sequence of general chemistry and how it affects their decision to persist to the second semester of general chemistry.

The findings reveal that course performance alone did not entirely explain students’ persistence to the second semester of general chemistry. While many students with strong grades continued, a notable portion of high-achieving students (including some who received A’s) did not progress to the second semester course (Edwards et al., 2023). Furthermore, the research found that first-semester performance did not predict students’ early second-semester course sense of belonging, suggesting that external factors, beyond academic success, influence students’ perceptions of belonging in chemistry courses. The findings emphasize that inclusive teaching practices, such as fostering social connection, and providing affirmation of student capabilities should be implemented throughout both semesters of general chemistry to improve persistence.

The research article by Fink et al. (2020) investigates the role of students’ sense of belonging in predicting academic success and retention in a two-semester general chemistry sequence. The study was conducted at a private, research-intensive university and involved first-year students enrolled in a two-semester sequence of general chemistry courses. The researchers collected data on students’ demographic backgrounds, academic preparation (including math scores, chemistry content knowledge, and AP coursework), participation in Peer-Led Team Learning (PLTL), and measures of perceived belonging and belonging uncertainty, which were surveyed at the beginning and end of the semester. The study’s methods involved using statistical analyses like ANCOVA, regression, and logistic regression to examine relationships between belonging, demographics, academic preparation, performance, and attrition.

The study found that academic preparation, including prior chemistry knowledge and AP coursework, positively predicted belonging, while students with weaker academic backgrounds felt lower belonging and higher uncertainty (Fink et al., 2020). Additionally, students’ early-semester belonging significantly predicted exam performance in both semesters, even after controlling for preparation, demographics, and PLTL participation. Higher belonging was associated with better exam scores, while higher belonging uncertainty was linked to lower performance in the second semester. Moreover, late-semester belonging in the first semester of general chemistry was a significant predictor of attrition, with students who felt lower belonging at the end of the semester more likely to leave the chemistry sequence before the second semester. The study concluded that a strong sense of belonging is an important factor for academic success and persistence in general chemistry.

Other student affective characteristics such as intellectual accessibility, emotional satisfaction, math self-concept, chemistry self-concept, self-efficacy, and test anxiety have been used to identify at-risk students in introductory chemistry courses (Chan & Bauer, 2014). Students in this study were required to take validated instruments such as the Chemistry Self-Concept Inventory (CSCI), Attitude toward the Subject of Chemistry Inventory (ASCI), and Motivated Strategies for Learning Questionnaire (MSLQ) to understand their cognitive and affective characteristics. Students with high scores on the survey instruments exhibited stronger beliefs in their performance of chemistry, more interest in science, and a better self-concept. In turn, students with higher scores on the survey instruments were significantly correlated to higher exam grades in their introductory chemistry course (Chan & Bauer, 2014). Students considered at risk had low beliefs of self-efficacy and self-concept and lower exam grades in the course. Social cognitive changes and student affective characteristics such as STEM interest and self-efficacy were also studied by Hardin and Longhurst (2016). Their research demonstrated that “lower self-efficacy, outcome expectations, and/or supports, as well as higher barriers predict lower interest and persistence in STEM” (Hardin & Longhurst, 2016, p. 234). Students with higher course grades demonstrated a stronger belief in their ability to perform in their introductory chemistry course. Student attitude was another characteristic investigated with student academic achievement in chemistry courses (Brown et al., 2015). The ASCI was given to students to quantify their attitudes and analyze performance on student assessments such as practical, tutorial, online web-based learning, and final exam. Overall, weak positive correlations were found between students’ attitudes toward chemistry and their final exam performance (Brown et al., 2015). The final study aiming to understand student characteristics and academic performance in undergraduate chemistry was performed by Van Duser et al. (2021). In this study, they looked at background characteristics of students rather than affective characteristics. Background characteristics of interest included a students’ prior ACT scores, SAT scores, and high school GPA. Both high school GPA and ACT math scores were found to be significant predictors of a student’s performance in introductory chemistry. This study also noted that there was a difference in the four instructors teaching chemistry, where students with instructor #1 were 2.6 times more likely to pass the course than students taking instructor #4 (Van Duser et al., 2021). Overall, students’ cognitive, affective, and background characteristics all play an important role in their academic achievement. Affective characteristics such as identity, self-efficacy, and motivation are more significant factors than a student’s attitude towards chemistry.

Student Learning. The way students approach learning in their introductory chemistry course was also revealed to be an important factor for academic success. Four studies investigated factors of student learning such as question logs, metacognitive processes, and learning styles. Bergey et al. (2023) examined student generated questions during chemistry lectures to understand their relationship to exam performance. Students wrote their questions in a log, and it was found that a higher number of questions generated during lectures correlated with lower levels of perceived comprehension. Students that found their questions were resolved during the lecture period reported higher levels of perceived comprehension. On average, students generated one to two questions per lecture, with a median of nine questions every lecture (Bergey et al., 2023). The type of questions that students produced also correlated to exam performance. Questions that sought verification or clarification were classified as closed syntax questions and resulted in better exam performance, but other question types and exam performance were not statistically significant in correlation (Bergey et al., 2023). Additionally, the study found that students improved in their metacognitive accuracy with the use of question logs for the first exam, but this did not continue for the remainder of the semester.

Another study of student learning sought to understand how students monitor and predict their exam performance over time. [Hawker et al. \(2016\)](#) asked students to report the grade they believed they would receive as a question at the end of their exams. This study saw a distinct difference in exam evaluations where students that performed highly on their exam had more accurate evaluations of their exam performance than those who scored poorly. A large majority of students (89%) were observed to estimate their exams at a higher grade than they performed ([Hawker et al., 2016](#)). Students were also observed to improve their metacognitive monitoring through exam evaluations immediately after the first exam but did not continue to improve significantly over time. [Cracolice and Busby \(2015\)](#) also examined student learning and its relation to academic success through factors such as alternate conceptions, intelligence, scientific reasoning ability, and attitude towards chemistry. Prior knowledge and the way that students conceptualized chemistry was found to be a significant predictor for performance on ACS exams. Students' scientific reasoning abilities were also significant predictors of exam performance ([Cracolice & Busby, 2015](#)). This study revealed that "both alternate conceptions about topics typically covered in first-semester general chemistry and scientific reasoning ability... influence general chemistry content knowledge after a semester of instruction" ([Cracolice & Busby, 2015](#), p. 1793). Alternate conceptions can be resistant to course content and negatively affect exam scores if students do not correct misconceptions.

Lastly, student's learning approaches at a Hispanic serving institution were analyzed to understand how they are related to chemistry course achievement. Final and ACS exam scores were used along with the Revised Approaches to Studying Inventory (RASI) to measure learning approaches as surface, strategic or deep ([An et al., 2022](#)). This study indicated that students increased in surface learning approaches and decreased in strategic and deep learning approaches over the semester, which suggests a shift towards rote memorization. Students with high strategic and deep learning approaches were observed to have the highest average ACS exam scores and course grades while those with high surface learning approaches had the lowest scores ([An et al., 2022](#)). This study demonstrated that the learning styles of students are directly linked to their academic performance in introductory chemistry. Studies included in this SLR highlighted that factors such as the way students approach learning and reflect on their learning processes play a significant role in their overall understanding of chemistry content.

3.2. Research Question 2: Student Success and Demographic Backgrounds

Research question two aimed to understand any differences in academic success based on demographic backgrounds of students in undergraduate introductory chemistry courses. There were 11 research studies that reported observed differences in academic success based on student demographics such as gender, race, and ethnicity.

Eight studies highlighted that academic outcomes were significantly different for students from historically underrepresented racial and ethnic populations. [Bancroft et al. \(2020\)](#) investigated student demographic differences based on a flipped instructional model intervention. They found that this model significantly improved course grades for Black and Latinx students as they were more likely to achieve higher grades in the flipped instructional model than in traditional lectures. This helped to close the achievement gap between Black and Latinx students compared to White or Asian students receiving the same flipped instruction. Interestingly, the flipped model introduced another performance gap between students from different socioeconomic backgrounds. Students from a low SES background showed much less improvement than students from mid to high SES backgrounds ([Bancroft et al., 2020](#)). Another study investigating active learning environments also reported differences for students in historically underrepresented populations. [Ott et al. \(2018\)](#)

sparingly discussed student demographic differences based on the implementation of a POGIL model in the introductory chemistry classroom. They found that historically underrepresented students in active learning environments using POGIL strategies were positively impacted, and overall achievement gaps were reduced (Ott et al., 2018). Specifics about the students from historically underrepresented groups were not provided in the study. Additionally, Harri et al. (2020) found that after controlling for academic experiences, students from underserved groups were more likely to persist in the course than their peers if they received a “C” or better grade, which was coined the “hyperpersistent zone”.

Revell (2014) also spoke briefly about the differences in student demographics based on the use of instructional technologies. It was found that students from international or ESL backgrounds used lecture replays more often, but the use of lecture replays was not significantly correlated to final exam performance in the course. Another study taking place at a Hispanic serving institution looked at the differences between Hispanic and non-Hispanic students with regard to their learning approaches and course performance (An et al., 2022). This study found that there were no differences in the learning approaches between Hispanic and non-Hispanic students. However, An et al. (2022) did find a small but statistically significant difference in the ACS exam scores of students that use strategic and deep learning approaches that favored non-Hispanic students when compared to Hispanic students.

Student affective characteristics based on expectancy-value theory was also noted to differ for students from different demographics. Perez et al. (2023) found that women, first-generation college students, and traditionally underrepresented racial and ethnic groups were overrepresented in profiles that had mixed values and costs and moderate to high confidence. This study observed that students from underrepresented populations tend to have higher costs, lower confidence, and less value associated with science. Women and traditionally underrepresented students also showed lower exam performance but no significant difference in long-term science persistence (Perez et al., 2023). Student demographic differences such as race and ethnicity were also investigated by French et al. (2023) in their study of understanding student motivations on their academic performance. This study concluded that there was “no evidence that students from underrepresented racial/ethnic groups reported lower initial chemistry motivation relative to students from well-represented racial/ethnic groups” (French et al., 2023, p. 306). A small and statistically significant finding demonstrated that students from underrepresented racial and ethnic groups had a lower final exam score than students from more well-represented groups. French et al. (2023) also found that attainment value was a stronger and more positive predictor of final exam scores for underrepresented racial and ethnic minorities compared to White and Asian American students. However, there was no evidence of confidence about performance, interest, utility value or attainment value differences for underrepresented and well-represented groups at the beginning of the semester.

The findings by Clark (2023) indicate that reformed courses significantly reduced achievement gaps for historically underrepresented students, even when in-class active learning was removed due to emergency remote teaching during the COVID-19 pandemic. However, the study found that gender-based performance gaps persisted, with male students consistently outperforming female students on exams, while female students performed better in laboratory assessments. The achievement gap based on gender does reverse in lab where females are performing better than males. Achievement gaps based on demographics remain fairly constant throughout the semester, but the gap is smaller and not always significant for gender differences on the final exam (Clark, 2023). The persistence of gender gaps suggests that additional interventions are needed to support female students in exam-based assessments.

The study by [Tashiro and Talanquer \(2021\)](#) examines the disparities in student performance based on sex and underrepresented populations in general chemistry courses. The study finds that reformed courses provide benefits for students with lower academic preparation, particularly in off-sequence courses (spring semester enrollment). Notably, female students outperformed male students in off-sequence courses, whereas in the on-sequence (fall) traditional course, male students had higher grades. Both the traditional and reformed courses showed that there were achievement gaps that favored males over females, but this gap was significantly reduced in the reformed course ([Tashiro & Talanquer, 2021](#)). The on-sequence reformed course demonstrated more equitable outcomes between sexes, suggesting that course structure and grading weight distribution influence academic disparities. Despite these improvements, racial and ethnic inequities persisted. The study observed that traditional courses placed heavier emphasis on exams, where male and white or Asian students performed better, while the reformed course incorporated more coursework-based assessments, benefiting female and historically underrepresented students.

In addition to differences in race and ethnicity, nine studies observed different academic outcomes based on gender. [French et al. \(2023\)](#) investigated gender differences in motivation and academic performance for students in introductory chemistry. Gender differences revealed that men reported greater confidence in their chemistry performance compared to women, but women reported greater utility and attainment values than men. The study also found that men performed slightly better than women on final exams ([French et al., 2023](#)). Another study by [Talanquer and Pollard \(2017\)](#) helped to narrow performance gaps for students from different gender groups based on their implementation of a reformed curriculum. Female students were shown to have a significant increase in their ACS exam performance, thus reducing the achievement gap for gender ([Talanquer & Pollard, 2017](#)). They also noted that students from underrepresented racial and ethnic groups benefitted from a significant improvement in their grade averages and reduced failure rates.

[Gulacar et al. \(2019\)](#) observed gender differences in their study of chemistry students' knowledge structures. Findings revealed that female students had more densely connected and cohesive knowledge structures than those of male students. Gender differences in the chemistry knowledge structures suggest that females and males have a different way of organizing and conceptualizing chemistry knowledge. Another study by [Hardin and Longhurst \(2016\)](#) sought to understand the gender differences in students' self-efficacy and interest and how this ultimately affected course outcomes in undergraduate chemistry. Their study found that "women demonstrated significantly lower STEM and coping self-efficacy and less STEM interest than did men" and men also "experienced a significant increase, on average, in perceived support for obtaining a STEM degree" ([Hardin & Longhurst, 2016](#), p. 237). The gender gap in academic performance did not narrow over the semester in the chemistry courses studied by [Hardin and Longhurst \(2016\)](#). The final research study investigating gender differences reported variances in student exam evaluations. It was observed that female students had higher rates of accurate evaluations of their exam performance compared to male students ([Hawker et al., 2016](#)). Females were found to have statistically significant and higher accuracy averages on three out of five semester exams compared to males. However, there was no significant difference in males and females with regard to their overall exam grades ([Hawker et al., 2016](#)).

The study by [Edwards et al. \(2023\)](#) examined the sense of belonging and persistence of students in the second sequence of general chemistry courses along with disparities based on gender differences. The study found that belonging uncertainty was a significant predictor of persistence for some female students, meaning that even when their grades

were comparable to male students, higher uncertainty about their belonging led some women to discontinue chemistry studies. Additionally, at the beginning of the second semester course, female students reported higher belonging uncertainty than their male peers, despite no significant gender differences in final grades from the first semester course (Edwards et al., 2023). The study concludes that fostering a sense of belonging and reducing stereotype threat is needed to help retain female students in general chemistry. Similarly to work by Edwards et al. (2023), another study by Fink et al. (2020) found that students' early sense of belonging in general chemistry, particularly in the first semester, varied by gender and race. Female students, especially those from historically underrepresented groups, reported lower belonging and greater belonging uncertainty compared to male students. Belonging is especially crucial for students from underrepresented backgrounds and women, who reported lower belonging and higher uncertainty, potentially contributing to disparities in performance and retention.

Only one study examined differences in student demographics related to financial need. In their study about student background characteristics and chemistry academic performance, Van Duser et al. (2021) looked at the receipt of Pell Grants to determine its relationship to chemistry achievement. This study found that the receipt of Pell Grants was not a statistically significant predictor of chemistry academic performance. Other studies lacked information related to students' socioeconomic status and their academic success.

4. Discussion

This SLR aimed to synthesize existing literature of undergraduate introductory chemistry courses to identify factors of student academic success (York et al., 2015) and any differences across varying groups of students. Our findings revealed that a large majority of studies used quantitative methodology. Of the mixed methods studies, only a few utilized focus groups or interviews to have direct interaction with chemistry undergraduate students. None of the research studies only used qualitative methodology to understand academic success in introductory chemistry undergraduates. Qualitative methods such as interviews and focus groups will utilize students' voices to fully understand their lived experiences and can provide richer details and context than quantitative methodology (Libarkin & Kurdziel, 2002). This SLR found a need for more qualitative research and case studies to understand how students make sense of their experiences in introductory chemistry courses.

Some of the research studies examined student performance in subsequent courses or credits taken in upperclassmen years. Many of the articles did not use a longitudinal study to understand academic performance and student outcomes over the course of their entire academic career. Studies presented in this SLR largely discussed academic success over the course of one semester, yet further insights can be gained from examining students over the course of several years. Institutions were largely U.S. based public universities with only international universities from Tanzania ($n = 1$) and Australia ($n = 2$). There is a need to investigate introductory chemistry courses at more international universities to gain insights into how institutions abroad promote academic success for their students. Additionally, many of the universities were public four-year institutions, with only one noted to be a minority serving institution (An et al., 2022) and another a U.S. Naval Academy (Bunce et al., 2017). This SLR shows a deficit in examination of institution types on student academic success in undergraduate chemistry. Historically Black Colleges and Universities (HBCU) serve an important demographic of historically underrepresented students and should be included in investigations of undergraduate chemistry courses. Moreover, none of the studies included private institutions such as Ivy League universities,

which could arguably have different expectations and factors of academic success than the studies included in this study.

Community colleges are also important academic institutions that are often under-recognized. Community colleges have been a growing entry point for students wanting to major in STEM (Snyder & Cudney, 2017), yet attrition in STEM is often highest at community colleges (Chen, 2013). Only one study (Gilewski et al., 2022) in this SLR used both a community college and public four-year university to investigate academic success for introductory chemistry undergraduates, but differences between the two institutions were not addressed. Community colleges cater to a diverse body of students, including a significant proportion of first-generation college students, low-income students, and students from underrepresented backgrounds (Cohen & Kelly, 2019). Despite their role in the STEM education pipeline, community colleges often operate with fewer resources than their four-year counterparts, yet they are tasked with the responsibility of preparing nearly half of the students who graduate with bachelor's and master's degrees in STEM fields (Hagedorn & Purnamasari, 2012). Considering that many community college students who come from low SES backgrounds are first-generation college students and maintain jobs while studying, it is unclear how academic interventions such as flipped instructional models may affect community college students. Future research efforts should be aimed at students in introductory chemistry courses at community colleges to understand how academic success may be different when compared to students at public four-year universities.

4.1. Factors of Academic Success in Undergraduate Introductory Chemistry

This SLR found three emergent themes for student academic success (York et al., 2015) in introductory chemistry courses: course design, instructional tools and resources, and student learning and characteristics. The theme of course design and learning environments saw many active learning environments utilized to promote students' academic success. Students in active learning environments have previously demonstrated the ability to retain more information and perform better on assessments than students in traditional learning environments (Bressoud, 2020; Clark, 2023; Freeman et al., 2014; Tashiro & Talanquer, 2021). Flipped instruction emerged as one of the active learning environments that helps promote student academic success in introductory chemistry courses. The flipped or partially flipped approach helps to reduce the cognitive load and working memory for students by allowing for them to take notes on prerecorded lectures outside of the classroom. Working memory is "affected by the inherent nature of material and by the manner in which the material is presented" (Kirschner, 2002, p. 4). The nature of chemistry requires students to understand submicroscopic concepts and connect them to the macroscopic world students are familiar with. Chemistry content comes with a plethora of new vocabulary, symbols, reactions, equations, and relationships for students to grasp. As a result, chemistry can cause substantial stresses to working memory as students try to organize and conceptualize information (Schuttlefield et al., 2012). Cognitive load theory assumes that students have a limited working memory and can only process a certain amount of information before being overloaded (Kirschner, 2002). This SLR highlighted instructional models focused on student-centered approaches such as flipped classrooms and POGIL models to help reduce strain for cognitive loads and working memory. Understanding the stressors that chemistry imparts on working memory and cognitive loads can lead chemistry instructors to design their courses in ways that facilitate more effective learning.

Only one of the studies (Msonde & Van Aalst, 2017) discussed online learning environments. Online learning has become popular in recent years with higher enrollment of online introductory courses, yet these courses have high rates of attrition compared to their in-person counterparts (Laing & Laing, 2015; Lederman, 2021). The area of research

concerning online learning environments for introductory chemistry is underrepresented in this SLR to fully understand how best to promote academic success for students in virtual introductory chemistry courses. In recent years, and particularly during the COVID-19 pandemic, online instruction has become a popular mode of instruction for students. Online learning can limit student interactions and isolate students from on-campus support systems (Laing & Laing, 2015; Lederman, 2021). Msonde and Van Aalst (2017) used student-centered approaches to help increase engagement and interactions among students in a virtual environment. Further research should look at effective online learning in chemistry courses to understand how these virtual environments can promote better educational outcomes for chemistry students given the traditionally higher attrition rates of online courses.

Many studies within the second emergent theme of course resources and feedback focused on assessments to improve student academic outcomes. One study (Tang et al., 2014) demonstrated how the complexity of stoichiometry problems are connected to a student's performance on the assessment. This study is also rooted in cognitive load theory as working memory is influenced by the manner in which chemical content is presented to students (Kirschner, 2002). Other studies highlighted the importance of student reflection and opportunities to engage with metacognitive processes through assessments. Metacognition, or thinking about thinking, can help students regulate their learning and develop a more profound understanding of chemical concepts (Lavi et al., 2019). This study revealed that assessments utilizing metacognitive prompts increased academic success for chemistry undergraduates. Additionally, it is important for students to link chemical concepts across topics to gain a deeper understanding of chemistry as a whole. Instructor feedback was observed to not only improve student grades but also promote student self-efficacy by affirming their abilities. Incorporating personalized instructor feedback on student assessments that utilize reflective, metacognitive, or crosslinking prompts can encourage students to engage more deeply with the curriculum rather than rely on rote memorization.

Other instructional tools and resources that were observed to promote academic success for students included the effective use of homework and quizzes. The more practice and engagement students have with course materials, the better their academic outcomes. This SLR did not uncover the use of innovative or alternative approaches such as technological tools and written assignments. Traditionally, chemistry courses do not provide students the opportunity to explore their own interests and engage deeply with course content (Bressoud, 2020; Bokosmaty et al., 2019). Alternative assessments, such as essays or papers, can be utilized to add more agency to student learning and allow students to investigate topics they are interested in. Student essays have been previously used in chemistry courses for students to write about their own passions and interests as it relates to the chemistry course (Asher et al., 2023). These student essays were seen to increase the persistence of students in STEM degree programs. Further research into instructional tools and resources that can foster agency among students is needed to understand any benefits to academic success and persistence in chemistry.

The final emergent theme revealed that student learning and characteristics were an important factor for academic success in introductory chemistry. Science identities and motivations as understood by expectancy-value theory were most often investigated to comprehend how student affective characteristics affect their course performance. Students that have high confidence in their abilities to succeed, value chemistry and science, and have low costs to participate in science, are those most likely to academically succeed (Brown et al., 2015; French et al., 2023; Perez et al., 2023). Specific academic interventions to help foster students' confidence or improve their value perception were not presented. This

SLR uncovered a need for further investigation of student identities using other theoretical frameworks aside from expectancy-value theory. Additional insights of students' identity and their affective characteristics can be gleaned from the use of theories such as identity-based motivation (Oyserman et al., 2017), self-determination theory (Black & Deci, 2000), or Bandura's social cognitive theory (Gryka et al., 2017).

One study (Smith et al., 2018) discussed the use of health-related scenarios in a general chemistry course for predominately nursing majors but did not look at student affective characteristics as a result of the more identity-congruent instruction. None of the studies presented in this SLR discussed student agency and the importance of students exerting choice and control over their learning. Students often take a passive role in STEM courses and do not have many opportunities for agency. It has been previously shown that adding more agency to student learning can help foster a sense of engagement and belonging in STEM through the use of innovative teaching methods (Ryoo & Winkelmann, 2021). Linking course content back to student's interests or future goals is especially needed considering the majority of students in introductory chemistry are not chemistry or biochemistry majors. Any efforts to connect course content to students' knowledge, experiences, and future goals could have profound impacts. Future research efforts can look at promoting student choice and design interventions to understand how they affect student learning and characteristics along with promoting academic performance.

It was also noted that studies did not specifically examine professors and how their professional development or pedagogical perspectives can help promote academic success of students. One study (Van Duser et al., 2021) observed differences in student academic performance and passing rates based on the instructor teaching the course, but did not provide details why this was the case. Van Duser et al. (2021) only sought to understand differences in student background characteristics and later uncovered the instructor differences in their analysis. Future research efforts should be aimed at understanding how professors come to develop and enact their personal pedagogies. Class observations were not a method identified in the 35 research articles in this SLR and would be beneficial for exploring professors' pedagogical practices in chemistry courses. There is an expansive literature base on educators' pedagogical content knowledge (PCK) and how it affects students' performance in primary and secondary education but seldom reciprocated in STEM higher education contexts (Fraser, 2016; Mahler et al., 2017; Park & Oliver, 2008). Chemistry instructors' PCK and student academic performance or persistence in STEM degree programs is an understudied area in STEM higher education.

4.2. Differing Factors for Varying Student Groups

Many studies analyzing the differences in student groups and academic performance focused on differences in student demographics such as gender, race, and ethnicity. Results from these studies indicated students from historically underrepresented populations such as Black, Hispanic, or female students, were at a higher disadvantage when compared to well-represented populations in STEM such as White or Asian males. Introductory chemistry courses often expose students to many American or European White males as many of the elements, compounds, structures, theories, equations, and chemical reactions are named after them. Students are aware that many of the individuals deemed important or significant in STEM do not come from a historically underrepresented background (Dancy et al., 2020). Current occupations in STEM also lack diversity, especially in engineering and computer science fields (National Center for Science & Engineering Statistics, 2023). When chemistry instructors are presenting important historical scientists in their course, they can also take the time to present scientists from underrepresented racial, ethnic, and gender groups. Research has shown that students personally identifying with a scientist

or role model in STEM are more likely to have interest in STEM and have a greater sense of belonging (Edwards et al., 2023; Fink et al., 2020; Gladstone & Cimpian, 2021). It is important for chemistry courses to teach about scientists that are reflective of the students taking the course in order to promote more identity congruence and a stronger sense of belonging for students. Many studies in this SLR only reported differences in student demographics and academic performance and did not discuss specific interventions that could be used to decrease achievement gaps and provide more equitable outcomes. There is a need for future studies to examine how students from historically underrepresented populations can be supported in introductory chemistry courses to overcome barriers of entry into STEM degree programs.

The Bancroft et al. (2020) study demonstrated that a flipped instructional model does not improve the academic success of all students in introductory chemistry courses. While the achievement gap closed for students from traditionally underserved groups such as Black and Latinx students, another performance gap was introduced for students from varying SES backgrounds. Flipped instruction requires students to use technology on their own time outside of the classroom to watch and take notes on prerecorded lectures. Students from low SES backgrounds may have more time restrictions than other students due to their own work responsibilities or family obligations based on their financial status. Studies in this SLR seldom discussed first-generation or low SES students. These backgrounds should be further investigated to understand student experiences of introductory chemistry courses with the goal of creating targeted supports. Academic resources should be leveraged to help students most at risk of dropping or failing their first semester in undergraduate gateway courses like chemistry.

Students enrolled in introductory chemistry courses are frequently majoring in other degree programs than chemistry- or biochemistry-related fields. None of the studies analyzed in this SLR looked at differences in academic performance based on the intended major of students. Examining student outcomes based on their intended major could provide insights into the degree programs that are most at-risk when taking chemistry courses and develop program-based interventions. Additionally, learning outcome differences were not analyzed between different institutions. Future studies can focus efforts at understanding any disparities that exist among different institution types such as public four-year universities, private universities, HBCU's, small liberal arts colleges, or community colleges. While differences in learning outcomes were observed based on achievement level, none of the studies targeted students that dropped out of the course to understand their experiences. Recruiting participants that have dropped, withdrew, or failed an introductory chemistry course would provide a deeper understanding of why they left and what they need to be academically successful. Studies are also needed to understand how students utilize academic resources such as textbook use, tutoring, and student-formed study groups to perform well in chemistry.

Lastly, student differences in academic performance were observed based on student affective characteristics, usually through the lens of expectancy-value theory. Students that had interest in STEM and stronger attitudes of STEM persisted through their chemistry course more often. Additionally, students that had high confidence in their STEM abilities, valued STEM, and exhibited low costs for participating in STEM were also more academically successful (Chan & Bauer, 2014; Perez et al., 2023). Even though student affective characteristics are strong predictors of their performance in introductory chemistry courses, only two studies examined differences in these variables on student learning outcomes. Future studies implementing targeted interventions to understand their effects on student affective characteristics are needed. Changing a students' perception of their identity, self-

efficacy, interest, and motivation in STEM can have profound impacts for STEM persistence and workforce development.

5. Limitations

A limitation of this study could be the inclusion of only two databases for this SLR. Our initial search included two additional databases (Google Scholar and Proquest). However, due to significant overlap in articles produced, we decided to focus on only two selected search engines. Potentially expanding this SLR to include more databases may have resulted in more studies, which may provide additional insights into the factors of academic success and student differences observed in undergraduate introductory chemistry courses.

6. Conclusions

Introductory chemistry serves as a gatekeeper course for undergraduate STEM degree programs and plays an important role in the retention and persistence of STEM graduates. This SLR revealed three key factors that contribute to introductory chemistry students' academic success including course design and learning environment, course resources and feedback, and student learning and characteristics. First, it is critical for an introductory chemistry course to move from traditional formats to a more student-centered, active-learning format. This could include using a flipped classroom model where students spend the majority of time in class working in collaborative groups and engaging actively with the content. The instructor should utilize formative assessment practices to gauge student learning during class meetings and provide real-time feedback during group work time. Second, creating access for students to chemistry content through strategies that build identity and motivation—seeing themselves as a successful person in chemistry—is key to engaging all students in the course including first-generation students, as well as those from historically underserved and underrepresented groups in chemistry and STEM overall. Creating access and building community within the introductory chemistry is critical for success—as the literature in this review indicated student demographics such as gender, race, and ethnicity are the most reported factors linked to disparities in academic outcomes in introductory chemistry.

The findings of this SLR highlight the need for targeted interventions to support equitable learning environments for a diverse group of students. Chemistry instructors should consider the use of active learning strategies and curriculum that can connect to students' experiences and future goals. Instructors should also consider the use of varied assessments and opportunities for reflection on metacognitive processes paired with constructive feedback for students. Additionally, chemistry interventions to promote students' lived experiences and science identity should be further developed to promote better educational outcomes for students.

There is a need for future research efforts to be focused on initiatives that address the barriers various groups of students encounter in introductory chemistry coursework. This can include the examination of mentorship programs, academic support services, and interventions to create a supportive learning environment. Through implementing the factors that influence academic success and working to eliminate disparities among groups of students, introductory chemistry courses can provide better educational outcomes for students along with increasing their persistence in STEM.

Author Contributions: Conceptualization, J.C. and C.C.J.; Methodology, J.C.; Validation, J.C.; Formal analysis, J.C. and C.C.J.; Data curation, J.C.; Writing—original draft, J.C. and C.C.J.; Writing—review & editing, J.C. and C.C.J.; Supervision, C.C.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Informed Consent Statement: Not applicable.

Data Availability Statement: An inventory of articles included in the systematic literature review are available along with the code sheet upon request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

- ACT. (2018). *The condition of STEM 2017*. ACT. Available online: https://www.act.org/content/dam/act/unsecured/documents/cccr2017/CCCR_National_2017.pdf (accessed on 16 February 2024).
- An, J., Guzman-Joyce, G., Brooks, A., To, K., Vu, L., & Luxford, C. J. (2022). Cluster analysis of learning approaches and course achievement of general chemistry students at a Hispanic serving institution. *Journal of Chemical Education*, 99(2), 669–677. [CrossRef]
- Asher, M. W., Harackiewicz, J. M., Beymer, P. N., Hecht, C. A., Lamont, L. B., Else-Quest, N. M., Priniski, S. J., Thoman, D. B., Hyde, J. S., & Smith, J. L. (2023). Utility-value intervention promotes persistence and diversity in STEM. *Proceedings of the National Academy of Sciences*, 120(19), e2300463120. [CrossRef] [PubMed]
- Bancroft, S. F., Fowler, S. R., Jalaiean, M., & Patterson, K. (2020). Leveling the field: Flipped instruction as a tool for promoting equity in general chemistry. *Journal of Chemical Education*, 97(1), 36–47. [CrossRef]
- Bergey, B. W., Cromley, J. G., Kaplan, A., & Bloxton, J. D. (2023). Do students' questions during chemistry lectures predict perceived comprehension and exam performance? *The Journal of Experimental Education*, 91(3), 411–430. [CrossRef]
- Black, A. E., & Deci, E. L. (2000). The effects of instructors' autonomy support and students' autonomous motivation on learning organic chemistry: A self-determination theory perspective. *Science Education*, 84, 740–756. Available online: [https://psycnet.apa.org/doi/10.1002/1098-237X\(200011\)84:6%3C740::AID-SCE4%3E3.0.CO;2-3](https://psycnet.apa.org/doi/10.1002/1098-237X(200011)84:6%3C740::AID-SCE4%3E3.0.CO;2-3) (accessed on 16 February 2024). [CrossRef]
- Bokosmaty, R., Bridgeman, A., & Muir, M. (2019). Using a partially flipped learning model to teach first year undergraduate chemistry. *Journal of Chemical Education*, 96(4), 629–639. [CrossRef]
- Bressoud, D. (2020). Talking about leaving revisited: Persistence, relocation, and loss in undergraduate STEM education. *Notices of the American Mathematical Society*, 67(09), 1. [CrossRef]
- Brown, S. J., White, S., Sharma, B., Wakeling, L., Naiker, M., Chandra, S., Gopalan, R., & Bilimoria, V. (2015). Attitude to the study of chemistry and its relationship with achievement in an introductory undergraduate course. *Journal of the Scholarship of Teaching and Learning*, 15, 33–41. [CrossRef]
- Bunce, D. M., Komperda, R., Dillner, D. K., Lin, S., Schroeder, M. J., & Hartman, J. R. (2017). Choice of study resources in general chemistry by students who have little time to study. *Journal of Chemical Education*, 94(1), 11–18. [CrossRef]
- Carpenter, T. S., Beall, L. C., & Hodges, L. C. (2020). Using the LMS for exam wrapper feedback to prompt metacognitive awareness in large courses. *Journal of Teaching and Learning with Technology*, 9(1), 79–91. [CrossRef]
- Chambers, K. A., & Blake, B. (2008). The effect of LearnStar on student performance in introductory chemistry. *Journal of Chemical Education*, 85, 1395–1399.
- Chan, J. Y. K., & Bauer, C. F. (2014). Identifying at-risk students in general chemistry via cluster analysis of affective characteristics. *Journal of Chemical Education*, 91(9), 1417–1425. [CrossRef]
- Chen, X. (2013). *STEM attrition: College students' paths into and out of STEM fields* (Statistical Analysis Report. NCES 2014-001). National Center for Education Statistics.
- Clark, T. M. (2023). Narrowing achievement gaps in general chemistry courses with and without in-class active learning. *Journal of Chemical Education*, 100(4), 1494–1504. [CrossRef]
- Cohen, R., & Kelly, A. M. (2019). Community college chemistry coursetaking and STEM academic persistence. *Journal of Chemical Education*, 96(1), 3–11. [CrossRef]
- Cosio, M. N., & Williamson, V. M. (2019). Timing of homework completion vs. performance in general chemistry. *Journal of Science Education and Technology*, 28(5), 523–531. [CrossRef]
- Cracolice, M. S., & Busby, B. D. (2015). Preparation for college general chemistry: More than just a matter of content knowledge acquisition. *Journal of Chemical Education*, 92(11), 1790–1797. [CrossRef]
- Dancy, M., Rainey, K., Stearns, E., Mickelson, R., & Moller, S. (2020). Undergraduates' awareness of white and male privilege in STEM. *International Journal of STEM Education*, 7(1), 52. [CrossRef]
- Edwards, J. D., Torres, H. L., & Frey, R. F. (2023). The effect of social belonging on persistence to general chemistry 2. *Journal of Chemical Education*, 100(11), 4190–4199. [CrossRef]

- Fayer, S., Lacey, A., & Watson, A. (2017). *Spotlight on STEM*; US Bureau of Labor Statistics. Available online: <https://www.bls.gov/spotlight/2017/science-technology-engineering-and-mathematics-stem-occupations-past-present-and-future/> (accessed on 16 February 2024).
- Figueroa, T., Cobian, K., Hurtado, S., & Eagan, K. (2017, March 4). *Trends and pathways for STEM major aspirants: A look at national data*. 9th Conference on Understanding Interventions That Broaden Participation in Science Careers Conference, San Antonio, TX, USA.
- Fink, A., Frey, R. F., & Solomon, E. D. (2020). Belonging in general chemistry predicts first-year undergraduates' performance and attrition. *Chemistry Education Research and Practice*, 21(4), 1042–1062. [CrossRef]
- Fraser, S. P. (2016). Pedagogical content knowledge (PCK): Exploring its usefulness for science lecturers in higher education. *Research in Science Education*, 46, 141–161. [CrossRef]
- Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, 111(23), 8410–8415. [CrossRef]
- French, A. M., Else-Quest, N. M., Asher, M., Thoman, D. B., Smith, J. L., Hyde, J. S., & Harackiewicz, J. M. (2023). An intersectional application of expectancy-value theory in an undergraduate chemistry course. *Psychology of Women Quarterly*, 47(3), 299–319. [CrossRef]
- Gilewski, A., Litvak, M., & Ye, L. (2022). Promoting metacognition through measures of linked concepts with learning objectives in introductory chemistry. *Chemistry Education Research and Practice*, 23(4), 876–884. [CrossRef]
- Gillespie, R. J. (1991). What is wrong with the general chemistry course? *Journal of Chemical Education*, 68, 192–194.
- Gladstone, J. R., & Cimpian, A. (2021). Which role models are effective for which students? A systematic review and four recommendations for maximizing the effectiveness of role models in STEM. *International Journal of STEM Education*, 8, 59. [CrossRef] [PubMed]
- Gryka, R., Kiersma, M. E., Frame, T. R., Cailor, S. M., & Chen, A. M. H. (2017). Comparison of student confidence and perceptions of biochemistry concepts using a team-based learning versus traditional lecture-based format. *Pharmacy Teaching and Learning*, 9(2), 302–310. [CrossRef]
- Gulacar, O., Milkey, A., & McLane, S. (2019). Exploring the effect of prior knowledge and gender on undergraduate students' knowledge structures in chemistry. *EURASIA Journal of Mathematics, Science and Technology Education*, 15(8), em1726. [CrossRef]
- Hagedorn, L. S., & Purnamasari, A. V. (2012). A realistic look at STEM and the role of community colleges. *Community College Review*, 40(2), 145–164.
- Hardin, E. E., & Longhurst, M. O. (2016). Understanding the gender gap: Social cognitive changes during an introductory stem course. *Journal of Counseling Psychology*, 63(2), 233–239. [CrossRef]
- Harri, R. B., Mack, M. R., Bryant, J., Theobald, E. J., & Freeman, S. (2020). Reducing achievement gaps in undergraduate general chemistry could lift underrepresented students into a “hyperpersistent zone”. *Scientific Advances*, 6(24), eaaz5687. [CrossRef]
- Hartikanean, S., Rintala, H., Pylvas, L., & Nokelainen, P. (2019). The concept of active learning and the measurement of learning outcomes: A review of research in engineering higher education. *Education Sciences*, 9(4), 276. [CrossRef]
- Hawker, M. J., Dysleski, L., & Rickey, D. (2016). Investigating general chemistry students' metacognitive monitoring of their exam performance by measuring postdiction accuracies over time. *Journal of Chemical Education*, 93(5), 832–840. [CrossRef]
- He, W., Holton, A. J., & Farkas, G. (2018). Impact of partially flipped instruction on immediate and subsequent course performance in a large undergraduate chemistry course. *Computers & Education*, 125, 120–131. [CrossRef]
- Kim, H., Chacko, P., Zhao, J., & Montclare, J. K. (2014). Using touch-screen technology, apps, and blogs To engage and sustain high school students' interest in chemistry topics. *Journal of Chemical Education*, 91(11), 1818–1822. [CrossRef]
- Kirschner, P. A. (2002). Cognitive load theory: Implications of cognitive load theory on the design of learning. *Learning and Instruction*, 12, 1–10.
- Kyne, S. H., Lee, M. M. H., & Reyes, C. T. (2023). Enhancing academic performance and student success through learning analytics-based personalised feedback emails in first-year chemistry. *Chemistry Education Research and Practice*, 24(3), 971–983. [CrossRef]
- Laing, C. L., & Laing, G. K. (2015). A conceptual framework for evaluating attrition in online courses. *e-Journal of Business Education & Scholarship of Teaching*, 9(2), 39–55.
- Lavi, R., Shwartz, G., & Dori, Y. J. (2019). Metacognition in chemistry education: A literature review. *Israel Journal of Chemistry*, 59(6–7), 583–597. [CrossRef]
- Lederman, D. (2021). *Detailing last fall's online enrollment surge*. Inside Higher Ed. Available online: <https://www.insidehighered.com/news/2021/09/16/new-data-offer-sense-how-covid-expanded-online-learning> (accessed on 16 February 2024).
- Libarkin, J. C., & Kurdziel, J. P. (2002). Research methodologies in science education: The qualitative-quantitative debate. *Journal of Geoscience Education*, 50(1), 78–86. [CrossRef]
- Lloyd, P. M., & Eckhardt, R. A. (2010). Strategies for improving retention of community college students in the sciences. *Science Educator*, 19(1), 33–41.

- Mahler, D., Großschedl, J., & Harms, U. (2017). Using doubly latent multilevel analysis to elucidate relationships between science teachers' professional knowledge and students' performance. *International Journal of Science Education*, 39(2), 213–237. [CrossRef]
- McDowell, L. D. (2019). The roles of motivation and metacognition in producing self-regulated learners of college physical science: A review of empirical studies. *International Journal of Science Education*, 41(17), 2524–2541. [CrossRef]
- Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook* (2nd ed.). Sage Publications, Inc.
- Msonde, S. E., & Van Aalst, J. (2017). Designing for interaction, thinking and academic achievement in a Tanzanian undergraduate chemistry course. *Educational Technology Research and Development*, 65(5), 1389–1413. [CrossRef]
- National Center for Science and Engineering Statistics (NCSES). (2023). *Diversity and STEM: Women, minorities, and persons with disabilities 2023* (Special Report NSF 23-315). Available online: <https://www.nsf.gov/reports/statistics/diversity-stem-women-minorities-persons-disabilities-2023> (accessed on 16 February 2024).
- NC State University Libraries. (2024). *Adult and higher education key databases*. Available online: <https://www.lib.ncsu.edu/databases/eric> (accessed on 16 February 2024).
- Ott, L. E., Carpenter, T. S., Hamilton, D. S., & LaCourse, W. R. (2018). Discovery learning: Development of a unique active learning environment for introductory chemistry. *Journal of the Scholarship of Teaching and Learning*, 18(4), 161–180. [CrossRef]
- Oyserman, D., Lewis, N. A., Yan, V. X., Fisher, O., O'Donnell, S. C., & Horowitz, E. (2017). An identity-based motivation framework for self-regulation. *Psychological Inquiry*, 28(2–3), 139–147. [CrossRef]
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., & Mulrow, C. D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, 372(71), n71. [CrossRef]
- Park, S., & Oliver, J. S. (2008). Revisiting the conceptualisation of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in Science Education*, 38, 261–284. [CrossRef]
- Perez, T., Robinson, K. A., Priniski, S. J., Lee, Y., Totonchi, D. A., & Linnenbrink-Garcia, L. (2023). Patterns, predictors, and outcomes of situated expectancy-value profiles in an introductory chemistry course. *Annals of the New York Academy of Sciences*, 1526, 73–83. [CrossRef]
- Philipp, S. B., Tretter, T. R., & Rich, C. V. (2016). Undergraduate teaching assistant impact on student academic achievement. *Journal of Science Education*, 20(2), 1–13.
- Porter, L. A., Chapman, C. A., & Alainiz, J. A. (2017). Simple and inexpensive 3D printed filter fluorometer designs: User-friendly instrument models for laboratory learning and outreach activities. *Journal of Chemical Education*, 94(1), 105–111. [CrossRef]
- President's Council of Advisors on Science and Technology. (2012). *Report to the president, engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics*; Executive Office of the President, President's Council of Advisors on Science and Technology. Available online: <http://files.eric.ed.gov/fulltext/ED541511.pdf> (accessed on 16 February 2024).
- Revell, K. D. (2014). A comparison of the usage of tablet PC, lecture capture, and online homework in an introductory chemistry course. *Journal of Chemical Education*, 91(1), 48–51. [CrossRef]
- Ryoo, J., & Winkelmann, K. (Eds.). (2021). *Innovative learning environments in STEM higher education: Opportunities, challenges, and looking forward*. Springer International Publishing. [CrossRef]
- Schreier, M. (2019). *Qualitative content analysis* (P. Atkinson, S. Delamont, A. Cernat, J. W. Sakshaug, & R. A. Williams, Eds.). SAGE Research Methods Foundations. [CrossRef]
- Schuttlefield, J. D., Kirk, J., Pienta, N. J., & Tang, H. (2012). Investigating the effect of complexity factors in gas law problems. *Journal of Chemical Education*, 89(5), 585–591. [CrossRef]
- Seymour, E., & Hewitt, N. (2000). *Talking about leaving: Why undergraduates leave the sciences* (pp. 1–448). Westview Press.
- Smith, A. L., Paddock, J. R., Vaughan, J. M., & Parkin, D. W. (2018). Promoting nursing students' chemistry success in a collegiate active learning environment: "If I have hope, I will try harder". *Journal of Chemical Education*, 95(11), 1929–1938. [CrossRef]
- Snyder, J., & Cudney, E. (2017). Retention models for STEM majors and alignment to community colleges: A review of the literature. *Journal of STEM Education*, 18(3), 48–57.
- Sorensen-Unruh, C. (2017). ConfChem conference on select 2016 BCCE presentations: Radical awakenings—A new teaching paradigm using social media. *Journal of Chemical Education*, 94(12), 2002–2004. [CrossRef]
- Stone, K., Shaner, S., & Fendrick, C. (2018). Improving the success of first term general chemistry students at a liberal arts institution. *Education Sciences*, 8(1), 5. [CrossRef]
- Stringfield, T. W., & Kramer, E. F. (2014). Benefits of a game-based review module in chemistry courses for nonmajors. *Journal of Chemical Education*, 91(1), 56–58. [CrossRef]
- Tai, R. H., Sadler, P. M., & Loehr, J. F. (2005). Factors influencing success in introductory college chemistry. *Journal of Research in Science Teaching*, 42, 987–1012.
- Talanquer, V. (2017). Concept inventories: Predicting the wrong answer may boost performance. *Journal of Chemical Education*, 94(12), 1805–1810. [CrossRef]

- Talanquer, V., & Pollard, J. (2017). Reforming a large foundational course: Successes and challenges. *Journal of Chemical Education*, 94(12), 1844–1851. [CrossRef]
- Tang, H., Kirk, J., & Pienta, N. J. (2014). Investigating the effect of complexity factors in stoichiometry problems using logistic regression and eye tracking. *Journal of Chemical Education*, 91(7), 969–975. [CrossRef]
- Tashiro, J., & Talanquer, V. (2021). Exploring inequities in a traditional and a reformed general chemistry course. *Journal of Chemical Education*, 98(12), 3680–3692. [CrossRef]
- Thomas, J., & Harden, A. (2008). Methods for the thematic synthesis of qualitative research in systematic reviews. *BMC Medical Research Methodology*, 45, 8. [CrossRef]
- Todd, K., Therriault, D. J., & Angerhofer, A. (2021). Improving students' summative knowledge of introductory chemistry through the forward testing effect: Examining the role of retrieval practice quizzing. *Chemistry Education Research and Practice*, 22(1), 175–181. [CrossRef]
- U.S. Bureau of Labor Statistics. (2020). *Employment in STEM occupations*. Available online: <https://www.bls.gov/emp/tables/stem-employment.htm> (accessed on 16 February 2024).
- Van Duser, K. E., Yan, X., Lucas, C. M., & Cohen, S. K. (2021). Predicting and supporting student performance in a high fail and high incompleteness course: An exploratory study of introduction to general chemistry. *College Student Journal*, 55(2), 135–144.
- Wang, Z., Adesope, O., Sundararajan, N., & Buckley, P. (2021). Effects of different concept map activities on chemistry learning. *Educational Psychology*, 41(2), 245–260. [CrossRef]
- Whalen, D. F., & Shelley, M. C. (2010). Academic success for STEM and non-STEM majors. *Journal of STEM Education*, 11(1), 45–60.
- Wong, R. M., Alpizar, D., Adesope, O. O., & Nishida, K. R. A. (2023). Role of concept map format and student interest on introductory electrochemistry learning. *School Science and Mathematics*, 124(1), 18–31. [CrossRef]
- Ye, L., Oueini, R., & Lewis, S. E. (2015). Developing and implementing an assessment technique to measure linked concepts. *Journal of Chemical Education*, 92(11), 1807–1812. [CrossRef]
- York, T. T., Gibson, C., & Rankin, S. (2015). Defining and measuring academic success. *Practical Assessment, Research & Evaluation*, 20(1), 5.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.