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# Understanding the reasons and cues that guide general chemistry students' studying decisions†

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With the prevalence of quantitative methods to examine student studying habits, this study harnesses qualitative methods to capture the reasonings behind general chemistry students' studying choices. Previous literature suggests that students use various strategies that may not be the most effective, according to learning scientists, and many studies that have implemented interventions to improve student study choices report mixed results. This study investigated the perspectives of 16 general chemistry I students regarding their studying decisions; perspectives were inductively analyzed using Self-Regulated Learning, Cognitive Load Theory, and Desirable Difficulties as lenses to frame our understanding. Results indicate that students heavily rely on their beliefs about a strategy's ability to help them understand/learn and prepare them for an assessment. Students are also influenced by instructor suggestions when choosing to use a strategy. When students discussed why they do not use strategies, they considered multiple cues related to learning/content, effort, and previous experience, including not valuing the strategy, not knowing how to use it, and not needing it. Implications for supporting improvements in student studying decisions are shared and aligned with students' specific reasonings and cues identified within the data.

## Background

### General student studying habits

Student studying habits have primarily been investigated using study habits questionnaires that focus on students' studying approaches and the breakdown of their studying time. Results from these studies indicate that students vary in their usage of the many different studying strategies available, with many students not consistently relying on the most effective studying strategies (*e.g.*, McCabe, 2011; Hartwig and Dunlosky, 2012; Wissman *et al.*, 2012; Dunlosky *et al.*, 2013; Bartoszewski and Gurung, 2015; Morehead *et al.*, 2016; Blasiman *et al.*, 2017). Some of these effective strategies, as evidenced by cognitive psychology, include spacing out studying over time, practices focused on recalling/retrieving information, elaborating to explain and describe ideas with many details, switching between ideas while studying, and using concrete examples to understand abstract ideas (Dunlosky *et al.*, 2013). Despite evidence that these strategies are effective, students tend to overuse less effective strategies, such as rereading course materials like textbooks and/or notes; more effective strategies, like practice testing and distributed practice, are underused by students (Gurung, 2005; Karpicke *et al.*, 2009; Gurung *et al.*, 2010; Bjork *et al.*, 2013; Blasiman *et al.*, 2017). A common reason that rereading course materials has been criticized as an ineffective strategy is its potential to produce a false sense of learning for students, thus prompting them with a sense of familiarity with the concepts after rereading their notes or textbooks, which may mislead them into believing they have achieved a mastery level of understanding (Koriat and Bjork, 2005; Kornell and Bjork, 2007; Dunlosky *et al.*, 2013; Blasiman *et al.*, 2017).

The prevalent use of less effective studying strategies may be caused by students' inaccurate understanding of the effectiveness of various studying approaches. For example, one study found that students were better at identifying and explaining why they considered their strategies effective, rather than discussing improvements to their methods or other strategies viewed as ineffective. This suggests that students may not realize when strategies are ineffective and continue to use them (Stanton *et al.*, 2019). When ranking different study strategies, students tend to rank practice testing low in terms of effectiveness, while ranking rereading and highlighting notes as highly effective (Blasiman *et al.*, 2017). A suggested reason for why students may think ineffective strategies are effective is their lack of formal training on effective studying strategies or how best to use strategies. This points to societal attitudes and assumptions within educational systems that individuals do not need to be taught how to manage their learning, emphasizing and valuing content delivery over effective

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studying strategies (Zimmerman, 1998; Bjork *et al.*, 2013). Along with not being taught effective learning behaviors, students often report that they do not need effective strategies to succeed at the primary and secondary levels (*e.g.*, K-12), causing them to continue to use ineffective strategies in postsecondary/collegiate settings (McGuire, 2006; Dye and Stanton, 2017; Ewell *et al.*, 2023).

Student reliance on ineffective study strategies contradicts expectations held by many college instructors that their students have well-developed studying behaviors, know how to prioritize studying, and already know and use effective strategies (Razali and Yager, 1994; Ewell *et al.*, 2023). Despite these expectations, instructors themselves have been found to advise students to use less effective studying strategies (*e.g.*, rereading the textbook) (Morehead *et al.*, 2016; Glogger-Frey *et al.*, 2018; Hunter and Lloyd, 2018; McCabe, 2018; Biwer *et al.*, 2020; Surma *et al.*, 2022; Ewell *et al.*, 2024). The lack of formal training for students was further evidenced in a survey of college students where most students "figured out" what they believed to be the best ways to study for themselves; without formal training, students must rely on their own experiences to make judgments about the effectiveness of strategies based on how the strategy impacts their performance on assessments, which may cause them to believe that ineffective strategies are more effective than they actually are (Kornell and Bjork, 2007; Stanton *et al.*, 2019). For example, many students mentioned general chemistry, organic chemistry, and biochemistry as courses that first caused them to evaluate their learning and studying approaches; most students only made changes based on external factors like earning an unsatisfactory grade (Dye and Stanton, 2017).

Students are also inconsistent in ranking the effectiveness of studying strategies and their actual use of specific strategies (Blasiman *et al.*, 2017; Dye and Stanton, 2017). For example, one study found that students report studying using ineffective strategies despite previously stating their belief that using effective strategies would help them perform better on exams and retain the material long-term, suggesting that students may have some knowledge of study strategy effectiveness even if they are not enacting those beliefs (Stanton *et al.*, 2015; Rea *et al.*, 2022). When questioned about what barriers prevented them from using active strategies, students reported the time and effort costs of using more effective strategies and concerns about using them effectively. This suggests that interventions must address students' perceived barriers rather than mainly focusing on metacognitive knowledge (Rea *et al.*, 2022). Another study suggested that the common use of mass practice (*i.e.*, cramming) before an exam may cause inconsistencies in student strategy ranking and usage. Students also believed that an ideal student studied around 20–30 minutes per day, gradually increasing several days before the exam; however, surveyed students only began studying two days before the exam. This behavior of relying on mass practice/cramming may cause students to select easier-to-implement strategies due to limited time, rather than strategies considered more effective or strategies that they initially intended to use (Blasiman *et al.*, 2017).

One way to think about how students learn is through the Student Approaches to Learning framework (SAL), which has been used previously to describe the choices students make when implementing deep or surface learning approaches (Marton and Säljö, 1976; Entwistle *et al.*, 1997; Ewell *et al.*, 2023). *Deep learners* try to connect their prior knowledge to new knowledge, using foundational concepts (*e.g.*, active strategies); *surface learners* tend to use algorithmic approaches that focus mainly on surface features or memorization (*e.g.*, passive strategies) (Entwistle *et al.*, 1997; Atieh *et al.*, 2021). Deep learning is considered the ideal approach to learning due to its connection to Novak's idea of Meaningful Learning (Novak, 1993). In contrast, surface learning is associated with extrinsic/performance-focused motivation (Lucas, 2001). Factors influencing students' choice to use deep or surface approaches include individual and course-specific factors, such as having well-developed metacognitive skills required to reflect on learning and choosing a strategy based on the assessment format. For example, multiple-choice exams can promote the use of surface approaches, while exams with open-response or essay-type questions can promote the use of deeper approaches (Feldt and Ray, 1989; Entwistle and Entwistle, 2003; Struyven *et al.*, 2005; Kember *et al.*, 2008; Jensen *et al.*, 2014; Ewell *et al.*, 2023). However, these explanations of students' studying decisions were primarily derived from closed-ended survey responses, rather than from conversations with students. This points towards the limitations of survey-only methodologies, where the reasons and rationales behind students' studying decisions may not be captured, resulting only in hypotheses for why students make their studying decisions. We seek to address this gap, called for in the literature, by discussing with students the various studying strategies they use and do not use, focusing on their rationales and reasonings for making their decisions (Sebesta and Bray Speth, 2023).

### Chemistry student studying habits

When exploring the various achievement groups of chemistry students, researchers have used a modified version of the two-scale Approaches and Study Skills Inventory for Students (ASSIST) to classify students as deep or surface learners (Entwistle *et al.*, 1997; Atieh *et al.*, 2021). When the shortened, modified version (M-ASSIST) was administered to general chemistry students, the surface scale was more sensitive than the deep scale (*i.e.*, the surface scale better differentiated between achievement groups based on final grades). When looking at students' scores on the deep and surface subscales, those with a below-average surface score and an above-average deep score performed better in the course, aligned with the theory. However, a high deep score did not always indicate a higher-performing student, as students with high surface scores were also among the lower-performing students. This suggests that some students may be deep learners who lack knowledge of effectively using deep approaches, resorting to surface approaches (Entwistle *et al.*, 2000; Atieh *et al.*, 2021). The intent to use deep approaches for these "high deep and high surface" students differentiates them from lower-performing students who rely solely on surface approaches. This further emphasizes the need for formal training to teach students what strategies are effective and how to use them productively (Entwistle *et al.*, 2000; Atieh *et al.*, 2021). When used with organic chemistry students, the M-ASSIST had similar implications, suggesting the need for longitudinal approaches when investigating students' studying strategies as changes occur between classes and semesters (Malinakova, 2022).

Interventions, particularly in chemistry courses, have focused on providing explicit study strategy and metacognition instruction. Although there have been reports of positive impacts on student study strategy choices (Muteti *et al.*, 2021), not all interventions successfully improve student study strategy choices and metacognition (*e.g.*, Stanton *et al.*, 2015; McDaniel and Einstein, 2020; Muteti *et al.*, 2023). This suggests that simply providing knowledge of study strategy effectiveness is not enough to cause students to change and leads to the need for additional intervention components that address the barriers students perceive that stop them from using effective strategies (Wang *et al.*, 2023). Overall, previous interventions to improve student studying decisions primarily lack student-level reasoning behind their studying choices and the specific barriers they face. This further supports the need for qualitative data on students' studying decisions.

While previous quantitative work provides insights for faculty on how to support student learning and effective studying decisions, the disruption of education brought on by the COVID-19 pandemic may have caused significant changes in student studying approaches (Gamby and Bauer, 2022; Hensley *et al.*, 2022; Boström *et al.*, 2023; Ramos and Towns, 2023). For example, one study found that students discussed a learning curve when entering college and needed help with their time management and study habits (Ramos and Towns, 2023). As such, it is necessary to understand the studying approaches of currently enrolled students. Additionally, qualitative data is needed to know how and why students choose different studying strategies, allowing for improved, data-driven interventions and teaching practices.

A recent study in chemistry harnessed qualitative methods and identified four factors that influenced chemistry student studying decisions: (1) the content of the exam, (2) the time efficiency of the strategy, (3) students' thoughts on the strategy's value (intrinsic value), and (4) students' perceptions of the strategy's influence on their performance (instrumental value). For example, students influenced by the exam's content adapt their studying behavior based on how conceptual they perceived the material or how much content there was. In contrast, those influenced by time efficiency adjust their behavior based on the perceived time efficiency of strategies when compared to each other. With students predominantly relying on one factor to guide their decision-making, interventions following a one-size-fits-all method may not be effective in improving studying behavior (Nayyar *et al.*, 2024). While these factors provide essential insights into students' decision-making process, study strategy-specific reasoning has been called for to develop effective interventions, especially by focusing on why students do not use effective strategies (Sebesta and Bray Speth, 2023).

## Theoretical frameworks

Three complementary theories—Self-Regulated Learning, Cognitive Load Theory, and Desirable Difficulties—have been combined to better understand student reasoning. Below, we define each framework before identifying the connections across frameworks (summarized in Fig. 1).

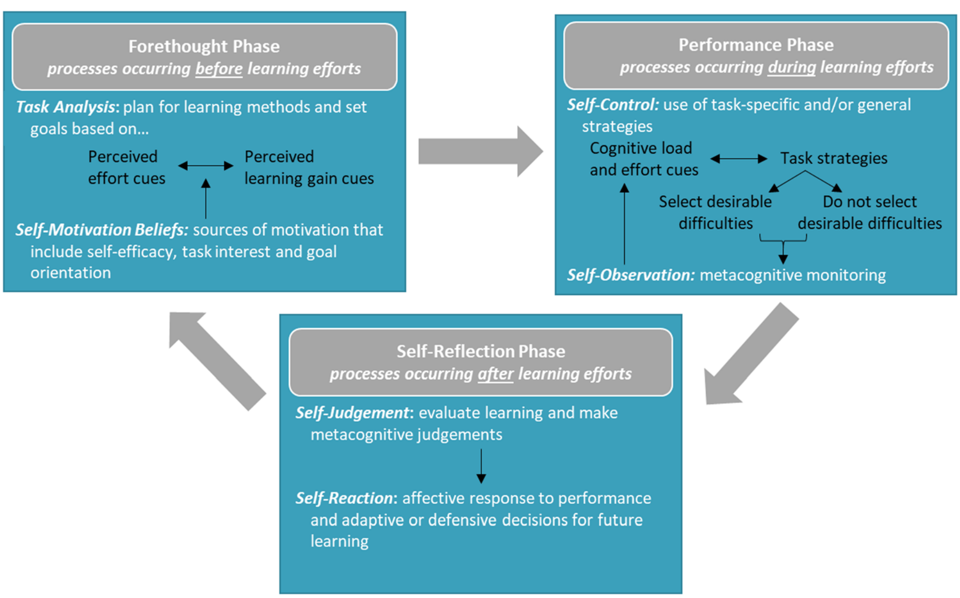


Fig. 1 An integrated model of Self-Regulated Learning, Cognitive Load Theory and Desirable Difficulties, informed by the cyclical model of self-regulated learning (Zimmerman and Moylan, 2009) and the dynamic integrative model of cognitive load and self-regulated learning (Wang and Lajoie, 2023), combined with desirable difficulties (Bjork and Bjork, 2014; De Bruin *et al.*, 2023).

### Self-regulated learning

Self-Regulated Learning is a process guided by cognition, metacognition, and motivation where learners plan their learning, enact learning strategies, and monitor and reflect on their learning (Zimmerman, 1990, 2008; Dignath and Büttner, 2008), and has been used in previous studies to analyze study strategy decisions (*e.g.*, Nayyar *et al.*, 2024). The cyclical model of Self-Regulated Learning has three phases (shown by the boxes in Fig. 1): forethought, performance, and self-reflection. The model includes a personal feedback loop where the learner uses their performance/outcome to inform future adaptations to their learning process (Zimmerman, 1990, 2008; Dignath and Büttner, 2008). The forethought phase involves any learning process or motivational source that occurs *before* learners start their efforts to learn and is composed of two parts: *task analysis*, where learners set goals and plan their learning, and *self-motivation beliefs*, where sources of motivation (*e.g.*, goal orientation, self-efficacy, and task interest/value) impact their goals and plans. For example, a student with a learning goal focused on improving their competence in the content by learning the material meaningfully (*i.e.*, a mastery goal orientation) has a better mindset for success and learning when compared to a student focused on getting a desired grade (*i.e.*, a performance goal orientation) (Pintrich, 1999; Muis, 2007; Naibert *et al.*, 2024). The forethought phase then impacts the student's preparation and willingness to self-regulate their learning during the performance phase. In the performance phase, the learner selects strategies (*e.g.*, time management and help-seeking) based on their forethought phase decisions and metacognitively monitors/reflects on their learning in the moment (Dignath and Büttner, 2008; Zimmerman and Moylan, 2009). The selected learning strategies impact their concentration and performance, leading to the self-reflection phase. The self-reflection phase consists of the *self-judgments* (*e.g.*, learners comparing themselves to others or their previous performance) and *self-reactions* (*e.g.*, learners adapting or not changing strategies) that occur after learning efforts and influence the next cycle of self-regulated learning (Dignath and Büttner, 2008; Zimmerman and Moylan, 2009).

### Cognitive load theory

Self-Regulated Learning has been modeled with Cognitive Load Theory to show how mental effort impacts all phases of Self-Regulated Learning. The connections between the two frameworks are depicted by the black arrows inside the self-regulated learning phases in Fig. 1. Cognitive Load Theory is based on the Information Processing Model and describes the amount of working memory occupied by a task (Sweller, 1988; Paas and Van Merrienboer, 1994; Wang and Lajoie, 2023). During the forethought phase, learners' perceptions about the cognitive demands of a specific task, based on the task's characteristics and the learner's prior knowledge, impact the goals they set and the learning methods they select. In the performance phase, learners choose strategies based on their cognitive load perceptions from the forethought phase and rely on cues to indicate their performance, as they cannot observe their cognitive state and task performance directly. These cues include the ease of processing the information (fluency), how difficult they believe the information is, and the necessary effort and time (Paas and Van Merrienboer, 1994; Wang and Lajoie, 2023).

The cue dealing explicitly with mental effort invested while learning has been modeled in the Effort Monitoring and Regulation framework, allowing the learner to evaluate their mental effort and adapt or maintain their current effort investment. The performance phase evaluations of effort are then used in the self-reflection phase to make metacognitive judgments about their learning, such as self-judgments of learning by estimating their exam performance (De Bruin and Van Merriënboer, 2017; De Bruin *et al.*, 2020; Wang and Lajoie, 2023). The mental effort invested and their task performance will determine how and what students select for the next learning task. If students perceive the effort they experienced as a cost that negatively impacts their motivation, there will be a decrease in motivation to use that strategy in the future. Suppose the strategy is compared against other strategies; in that case, the effort can be viewed as a perceived cost, and the less effortful strategy will be judged as better for learning. This negative view of effort contributing to less effective learning is a common perception that learners have about highly effortful strategies, also known as desirably difficult strategies (Zeegers, 2001; De Bruin *et al.*, 2023; Wang and Lajoie, 2023).

### Desirable difficulties

When students select studying strategies during their self-regulated learning process, they may select tasks considered "desirably difficult" for the performance phase (see Fig. 1). Desirable Difficulties describe learning tasks that are considered effective yet difficult, by requiring an amount of effort considered desirable for meaningful learning (Smith *et al.*, 1978; Bjork and Bjork, 2014; Walck-Shannon *et al.*, 2021). For example, this framework suggests that active strategies where learners create a strategy or self-assess themselves are more effective and lead to better performance on exams than passive strategies (*e.g.*, rereading notes). Other learning conditions reported to be desirably difficult include varying learning conditions, interleaving instruction on separate topics, spacing out study sessions, and using practice testing. The challenges experienced using these approaches lead to more long-lasting and flexible learning (Hartwig and Dunlosky, 2012; Rodriguez *et al.*, 2018; Walck-Shannon *et al.*, 2021; Ewell *et al.*, 2023; Laguerre Van Sickle and Frey, 2025). However, Expectancy–Value–Cost theory suggests that student engagement in behaviors depends on their perceptions of the likelihood of success, the value of the outcome, and/or the task cost or effort; this may cause students not to use desirably difficult strategies due to the high effort required (Flake *et al.*, 2015; Kirk-Johnson *et al.*, 2019; Wilkes *et al.*, 2024). For example, practice testing has been reported as underused and not viewed by students as effective for learning; this lack of awareness of effectiveness may be caused by students seeing practice testing as existing only for assessment purposes rather than for learning. Instead, students report overusing rereading notes and not taking advantage of the pedagogical benefits of practice testing, including the metacognitive benefits from determining if information has truly been understood nor the increase in effectiveness of later learning opportunities (Kornell *et al.*, 2009; Bjork and Bjork, 2014; Blasiman *et al.*, 2017).

Strategic planning (*i.e.*, planning to use a strategy considered desirably difficult) falls into the forethought phase of Self-Regulated Learning as students use their prior knowledge and experiences to choose or construct advantageous learning methods. The lack of formal training on what strategies are effective and how best to use these strategies has been reported in the literature and can cause learners to rely only on their experiences when selecting strategies (Zimmerman, 1998; Kornell and Bjork, 2007; Bjork *et al.*, 2013). If students are unaware of effective strategies or do not consider them effective for their learning, they will not select the strategy during the performance phase. In addition, if learners lack background knowledge or skills to respond to the difficulties brought on by more effortful strategies, the difficulty becomes undesirable and will not result in the same learning benefits. While in the performance phase, practice testing can help students metacognitively monitor their learning and adjust their strategies accordingly. However, the challenges introduced by Desirable Difficulties may decrease students' judgments of their rate of learning. These perceptions of students while they are metacognitively monitoring themselves may lead students to avoid challenging strategies in the future if they view the effort as not worth the payoff (Kornell and Bjork, 2007; Kirk-Johnson *et al.*, 2019). In the study described herein, students' effort considerations (Desirable Difficulties and Cognitive Load Theory), insights on the effectiveness of strategies for themselves and/or for the studied content (Cognitive Load Theory, Desirable Difficulties, and Self-Regulated Learning), and their previous experiences (Self-Regulated Learning) provide cues to understand better what impacts student studying decisions.

## Research questions

This study focuses on understanding chemistry students' studying decisions by asking students directly about the reasons behind their choices. As such, we seek to address the following research questions:

1. What study strategies do students use in their General Chemistry I course?
2. What common reasons and cues do students have for using studying strategies?
3. What are students' common reasons and cues for not using studying strategies?

## Methods

The study was conducted at a large university in the Northeast of the United States during the Fall 2022 semester; the Institutional Review Board approved the study before any data collection. In 2022, the institution's undergraduate student body was approximately 33% first generation, 57% female, and 73% white (The University of Rhode Island Office of Institutional Research, 2022; The University of Rhode Island Division of Student Affairs, 2022). Participants were recruited from multiple sections of a traditional General Chemistry I course, offered for both STEM and chemistry majors, with an enrollment of approximately 900 students each semester (Fig. 2). The sample was drawn from 13 different sections of General Chemistry I, taught by 6 different instructors. While each instructor had autonomy in their course structure, all sections shared learning outcomes. Additionally, each section had approximately four exams per semester, with a mixture of multiple-choice and short answer depending on the individual instructor's preferences.

To recruit students for the study (see Fig. 2), individual course instructors distributed a recruitment survey to their students, comprised of two study habit questionnaires and demographic questions (*e.g.*, gender, major, enrolled section/instructor, if they have a job during the semester) (Estes and Richards, 1985; Malinakova, 2022). As an incentive to encourage participation, participants were entered into a drawing for one $25 Amazon E-gift card for every 50 survey responses. In total, 126 students (14% of average student enrollment) responded to the recruitment survey (*i.e.*, volunteered to participate in the study); from these volunteers, individuals were invited after their first exam to participate in a semi-structured interview to understand better how they studied, considering that student study intentions do not always match their actions (Blasiman *et al.*, 2017). Invitations to participate in these interviews were informed by purposeful sampling – the research team sought to ensure the interviewed sample had maximum variation by diversifying in terms of course section enrolled, gender, ethnicity, major, overall responses to the study habit questionnaires, and whether or not students had a job during the semester (Patton, 2002). Ultimately, 16 students (1.7% of average student enrollment) accepted our invitation and participated in an interview. After completing the interview, students were compensated with a $10 Amazon E-gift card. Exam and course grades for participants were not collected, preventing any analysis relating achievement to study strategy patterns.

The interview guide was informed by study habits questionnaires and previous work investigating student study habits, along with findings from learning scientists regarding effective studying strategies (*e.g.*, Wong, 1985; Mayer and Anderson, 1992; McDaniel and Donnelly, 1996; Benjamin and Tullis, 2010; Roediger Iii *et al.*, 2011; Rohrer, 2012; Rawson *et al.*, 2015). The semi-structured interview guide had six phases: (1) background and context to confirm demographics (*e.g.*, the student's major, ethnicity, gender identity) and understand their experiences in chemistry (*e.g.*, previous experiences and their goal grade for the course), (2) how they prepare for a chemistry exam, (3) their motivation related to their chemistry class (*e.g.*, mastery or performance goal), (4) the impact of satisfactory and unsatisfactory grades and peer comparisons on their studying decisions, and (5) how they manage their time (*e.g.*, how much time they spend studying) and how obstacles (*e.g.*, jobs, distractions) impact their studying. The interview's

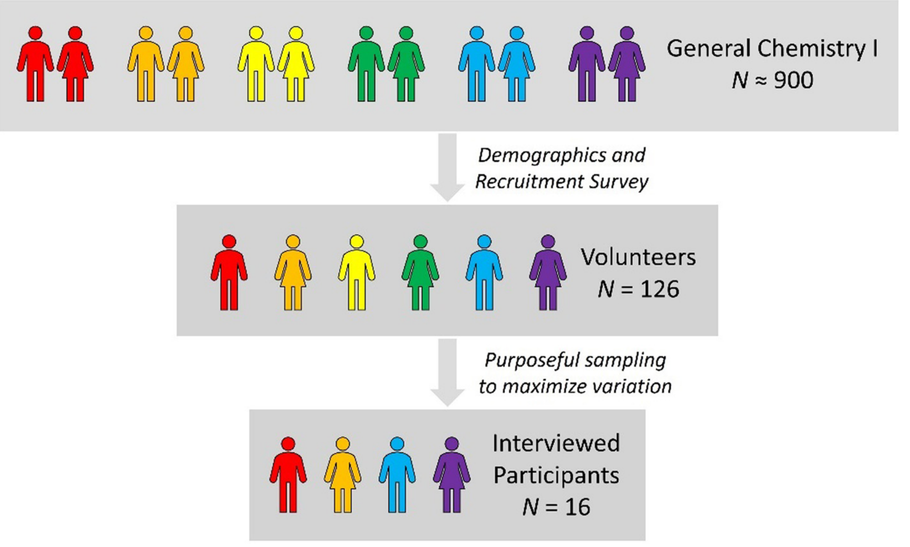


Fig. 2 Recruitment of interviewed participants, sampled from volunteers from the General Chemistry I population.



exam preparation and time management sections connect to the forethought and self-reflection phases of Self-Regulated Learning, as students talked about how they plan their studying and how any reflections from using the strategies previously impacted their choices. The motivation section targeted self-motivation beliefs in the forethought phase, while the section discussing the impact of grades and peer comparisons focused on the self-judgements students make and how they impact their self-reactions in the self-reflection phase.

Only responses to interview phase 2 (exam preparation) are presented herein, focusing specifically on the study strategies that students use and do not use. This interview phase began with an open-ended discussion about how the student generally studies for their chemistry exams to understand their thoughts. Afterward, they were prompted with a checklist of study strategies reported in the literature and resources available in the institutional context (Blasiman *et al.*, 2017; Atieh *et al.*, 2021; Fergus *et al.*, 2021). This checklist was created in response to two pilot interviews with undergraduate students who had previously completed the general chemistry sequence; responses were sparse, not very deep, and capturing responses *via* field notes was challenging. As such, the checklist was created to allow for a physical record of what study strategies and resources students reported using and to elicit more insights into student study strategies, particularly for ones they may have forgotten about or did not realize were strategies (Zhao *et al.*, 2014; Chan and Bauer, 2016; Muteti *et al.*, 2023). When discussing the strategies in the checklist, students were asked to explain *why* they use or do not use each study strategy. After the open-ended questions and the checklist discussion, students were also asked how they learned to study and if their instructor recommended any study strategies, providing further context.

Each interview lasted approximately 60 minutes, was audio recorded, and transcribed verbatim. Each participant was randomly assigned a pseudonym to support confidentiality, and ATLAS.ti was used to manage data and code transcriptions (ATLAS.ti Scientific Software Development GmbH, 2024). To address research question 1, students' open-ended responses and discussions of the study strategy checklist were used to record the number of students using each study strategy. The study strategies were categorized into three types based on their source to aid interpretation: Externally Provided Strategies, Student Created Strategies, and Social Learning Strategies. Externally Provided Strategies were obtained from sources other than the student, such as the instructor or the internet. Student Created Strategies were those directly created by the student (*e.g.*, their notes and their own study guide). Social Learning Strategies involve interactions with another human, such as seeing a tutor or studying with a peer. Dividing the strategies into these three categories allowed for identifying overarching patterns based on similar study strategies.

To address research questions 2 and 3, inductive (open) coding was used to examine students' unique reasons (Patton, 2002). Inductive coding involved multiple research team members individually coding transcripts before attending weekly debriefing meetings where developed codes were discussed and agreed upon (Fig. 3). Any disagreements in code applications were discussed until 100% agreement was reached (Lincoln and Guba, 1985; Saldaña, 2021). Coding/analysis was purposeful in keeping track of the specific study strategy discussed, the student's reason(s) related to the strategy, and whether the student used the strategy. With the overwhelming number of reasons discussed by students, individual student reasons were grouped into broader categories to understand their studying decisions better. Inductive coding was used to capture students' reasons in their own words; an additional analysis used deductive coding where responses were coded through the lenses of our theoretical frameworks (Fig. 1); the frameworks provided deductive cues related to what students relied on when making their decisions: learning/content, effort, and previous experience (Saldaña, 2021). Inductive and deductive findings had significant overlap; as such, the manuscript

 

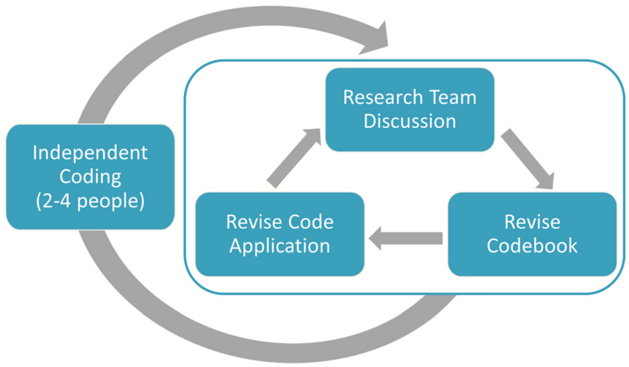


Fig. 3 Overview of the qualitative coding and analysis process.



Table 1 Student demographic information

| Demographic variables | Students, $n^a$ |
|---|---|
| Gender identity | |
| Female | 10 |
| Male | 5 |
| Prefer not to answer | 1 |
| Major | |
| Engineering | 4 |
| Pharmaceutical Sciences | 3 |
| Animal Science | 2 |
| Biology | 2 |
| Marine Biology | 2 |
| Neuroscience | 2 |
| Chemistry | 1 |
| Criminal Justice | 1 |
| Ethnicity identity | |
| White | 9 |
| Asian | 2 |
| Prefer not to answer | 2 |
| Black or African American | 1 |
| Middle Eastern | 1 |
| Indigenous Latino | 1 |
| Generation status | |
| First-generation students | 4 |
| Job status | |
| Has a job during the academic year | 5 |

[a] $N = 16$.

focuses explicitly on the inductive coding/student words, while deductive findings are shared in the ESI,† for those interested.

With qualitative methods, it is essential to provide evidence to support the trustworthiness of the findings and interpretations (Lincoln and Guba, 1985; Shenton, 2004). When developing the interview guide, two pilot interviews were conducted with students who had previously completed the general chemistry sequence. This helped ensure that the interview guide questions elicited meaningful data to address the research questions, including whether students interpreted questions as intended. These interviews resulted in the development of the study strategy checklist to address limitations in elicitation. When developing the inductive reason codes, research team members (2–4 researchers) independently coded before meeting weekly to discuss/revise codes and their applications, with any disagreements discussed until a consensus was reached. Preliminary interpretations of data and findings were also presented to research group members at the same institution who were not involved with the project, and those attending national research conferences. These opportunities provided peer scrutiny to improve the work and our overall interpretation. Overall, pilot testing interview questions, all data being coded by at least two researchers, weekly debriefing meetings, and multiple peer scrutiny opportunities all provide evidence to support the trustworthiness of our interpretations and conclusions.

## Results and discussion

The 16 interviewed students were fairly representative of the institutional population regarding gender and ethnicity identities (see Table 1), including being predominantly female (57%), white (73%), and continuing-generation students (66%). Additionally, the reasons and cues discussed by students became repetitive after 12 interviews, allowing four additional interviews to provide evidence for data saturation. Overall, given the range of students who enroll in General Chemistry I, our sample includes various majors. It is important to note that all findings were analyzed through the lens of these demographics to understand any patterns/trends based on gender, major, ethnicity, *etc.* No patterns or trends were identified across any demographic variable. This is not surprising, given the personal nature of studying and decision-making. However, it is worth mentioning the lack of demographic patterns. The sample size may be impacting this result, limiting the transferability of these findings to other contexts despite evidence for data saturation. Despite this, patterns were identified across study strategy types that provide useful insights for chemistry education and are explored in more detail below.

Before discussing the study approaches students use and their reasoning, it is essential to provide some context by describing how the participants learned to study. Only four students ($n = 4$, 25%) described formal training/instruction on effective study strategies and approaches. Albert described training through a university-specific study strategy course: "*...I did have [the University studying course] and they did give us a bunch of studying tools...that's where I got the Cornell [notetaking] method stuff too.*" In contrast, Lily had formal training early on in her educational experiences:

*I think I learned how to study pretty early on in...the elementary school I went to...[was] very big on test scores and test grades, so we would literally spend classes trying to better understand, ya'know, are you an auditory...learner? Are you a visual learner? ...I've known since like second or third grade that I am very much a visual learner or a hands-on learner.*

Both Albert and Lily revisited these ideas while discussing their reasons for using or not using specific study approaches. Lily's discussion also highlights the persistent idea of learning styles, despite the lack of evidence (Pashler *et al.*, 2008; Morehead *et al.*, 2016; Bretz, 2017; McCabe, 2018; Biwer *et al.*, 2020), which was perpetuated by her previous instructors and educational experiences. Two students discussed the importance of aligning their studying strategies with their learning style. For example, Percy said "*I create visuals to represent the material [be]cause I'm as I said I'm a hands on learner and so a visual like a balloon or like some-like a doodle will help me better*." Targeting learning styles in future interventions, particularly for instructors, may be worthwhile. Regardless, it is positive that students are using their prior experiences in teaching and learning settings to make their studying decisions, in line with self-regulated learning (Zimmerman and Moylan, 2009).

Overall, it was not common for students to have formal experience or training on effective studying strategies ($n$ = 12, 75%), in line with previous research (Zimmerman, 1998; Kornell and Bjork, 2007; Bjork *et al.*, 2013). This leads students to use their own experiences to inform their study approaches. For example, Rose uses her perceptions: "*I just go with what I think studying should be*." Similarly, Minerva uses her preferences to form her habits and calls out the lack of training in her education: "*In…middle school and high school, they didn't teach us like exactly how to study but it was just preference…*" Charlie described figuring out what studying approaches worked best for him: "*How did I learn how to study? …Umm trial and error I guess, seeing what works and what doesn't*." Overall, the lack of training results in students using a variety of experiences and assumptions to form their ideas about effective studying approaches. As such, to design interventions and strategies to help students develop more effective studying approaches that align with learning science, the study strategies used by students and their reasonings must be explored; therefore, we first report the study strategies used by students before exploring their reasons.

**RQ1: What study approaches do students use in their General Chemistry I course?**

Students used a variety of study strategies across the three overarching types (see Fig. 4), in line with previous findings that students vary in their usage of different strategies (Dunlosky *et al.*, 2013; Bartoszewski and Gurung, 2015; Blasiman *et al.*, 2017). Of the three overarching study strategy types, Externally Provided Strategies were the most prevalently used; more than half of the sample discussed using every Externally Provided Strategy, excluding redoing homework questions. These commonly used strategies are often directly provided to students (*e.g.*, reading the instructor's notes) or readily available/accessible (*e.g.*, watching videos online) compared to other strategies. Reading notes, whether it be their instructor's notes or their notes, were used by all students. Such a prevalence of reading notes echoes previous findings that students overuse rereading notes and consider it highly effective for their learning (Gurung, 2005; Karpicke *et al.*, 2009; Gurung *et al.*, 2010; Bjork *et al.*, 2013; Blasiman *et al.*, 2017; Laguerre Van Sickle and Frey, 2025), despite findings suggesting otherwise (Koriat and Bjork, 2005; Kornell and Bjork, 2007; Dunlosky *et al.*, 2013; Blasiman *et al.*, 2017).

Student Created Strategies were the second most used strategies. Despite the lower prevalence, Student Created Strategies were also used by more than half of the sample. While some student created strategies require significant effort (*e.g.*, making a practice test or study guide), the more commonly used Student Created Strategies are more straightforward to

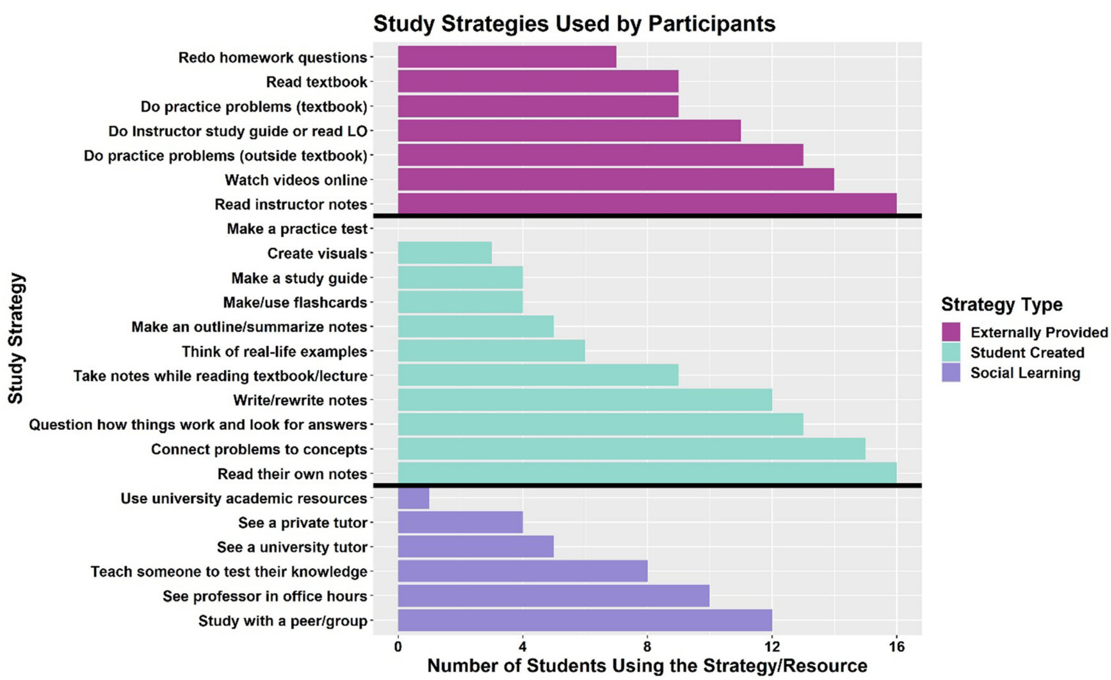


Fig. 4 Number of students using specific studying strategies. *Note: horizontal lines are used to delineate the three types of study strategies – Externally Provided Strategies on top, Student Created Strategies in the middle, and Social Learning Strategies at the bottom.*

 

use (*e.g.*, reading and rewriting their own notes). The more effortful strategies being less commonly used (*e.g.*, making flashcards, outlining, thinking of real-life examples) aligns with previous work on student-studying approaches (Gurung, 2005; Karpicke *et al.*, 2009; Blasiman *et al.*, 2017; Chouvalova *et al.*, 2024). The more effort students must invest in a strategy, the higher its perceived cost. This can decrease their motivation to use it. Instead, students commonly use less effortful strategies and judge them as more effective for their learning (Zeegers, 2001; De Bruin *et al.*, 2023; Wang and Lajoie, 2023). However, previous work in this area emphasizes the unique nature of student studying decisions; while some findings suggest that students less commonly use effortful strategies, others report that specific effortful strategies (*e.g.*, making flashcards) are some of the most widely used study strategies (Karpicke *et al.*, 2009; Morehead *et al.*, 2016; Chouvalova *et al.*, 2024). As such, understanding the various reasons students have for choosing their studying approaches is necessary.

Significantly, no students discussed making their own practice test, in line with reported under usage of practice testing and students ranking practice testing as a less effective studying strategy; this has been attributed to the added effort required to use this strategy, as well as students viewing practice testing as only for assessment rather than for learning or studying (Karpicke *et al.*, 2009; Kornell *et al.*, 2009; Gurung *et al.*, 2010; Bjork and Bjork, 2014; Blasiman *et al.*, 2017). Despite not creating practice tests as part of their approaches, students report using other strategies for self-assessment purposes, described in more detail below as part of why they select different strategies (research question 2).

Social Learning Strategies were the least commonly used approaches. However, every student described using at least one Social Learning Strategy, suggesting that students may implicitly understand the benefits of social learning (Vygotsky and Cole, 1978). As discussed below, students primarily described Social Learning Strategies through the lens of help seeking (*e.g.*, seeing a tutor or going to a professor's office hours); this is contrary to previous work that suggests that students do not always seek help when needed (Won *et al.*, 2021). Studying with peers was the most used Social Learning Strategy, following the reported trend of students preferring their peers when seeking help, which has been attributed to improved studying (Gettinger and Seibert, 2002; Beisler and Medaille, 2016; Li *et al.*, 2023; Wally *et al.*, 2023). When discussing Social Learning Strategies outside of peers, students often chose their instructors over university resources, with only one student using university academic resources for help with time management. Overall, the specific studying strategies used by sampled students align with previous work across disciplines. Having discussed the students' studying choices, we now move to their reasons for using study strategies.

### RQ2: What common reasons and cues do students have for using studying approaches?

While knowing which studying strategies the sampled General Chemistry I students use is valuable and practical, understanding the reasons these students have for using or not using specific strategies provides more tangible insights and implications for chemistry teaching and learning. Additionally, studying habits have primarily been investigated using surveys to report what students do and suggest potential reasons for why students are making their choices. However, to better design interventions to help students improve their studying habits, the reasons behind student choices must be captured rather than relying on expert hypotheses.

Given the unique nature of student beliefs and epistemologies (Ridgeway *et al.*, 1998; DeGlopper *et al.*, 2023), it is unsurprising that a wide variety of reasons were identified in the dataset, with unique patterns specific to individual students. Each student discussed 15–29 reasons why they chose to use or not use a studying strategy. When disaggregating reasons by whether they are for using or not using strategies, students discussed 7–19 reasons for why they chose to use a strategy and 6–15 reasons for why they chose not to use a strategy. To make sense of such complexity, we report the categorization of individual student reasons into broader categories (bolded for easier identification) based on why or how a student chose to use a studying strategy.

**Student reasons for using studying strategies.** To provide better insights and nuance, we start by describing the five reason categories discussed by students and their prevalence across all strategies before breaking down the reasons by study strategy types. The reason categories for using strategies included decisions based on: (1) **their understanding/learning**, (2) **idiosyncratic/personal reasons**, (3) **their assessments**, (4) **their instructor**, and (5) **reflection/metacognition** (see Table 2). **Decisions based on understanding/learning**, discussed by all students, focused on students using specific studying strategies because they believe they benefit their learning and understanding of the content. For example, see Minerva's quote in Table 2, which discusses the need for supplemental learning, so she used online videos to understand the content better. The consideration of learning when selecting a strategy is a positive indication that students are evaluating the effectiveness of strategies before adopting them, in line with the forethought and self-reflection phases of Self-Regulated Learning (Zimmerman and Moylan, 2009).

**Decisions based on idiosyncratic/personal reasons**, also discussed by all students, were more unique to individuals and ranged from generic preferences for strategies to more specific reasons (*e.g.*, wanting an in-person/physical resource instead of a virtual/online resource). For example, Millicent (see Table 2) discussed making her own notes that were organized in a way that she perceived as better for her studying. In contrast to **decisions based on understanding/learning**, **decisions based on idiosyncratic/personal reasons** had a greater variety, with fewer students sharing the same idea. Such variety is expected given the personal nature of studying and the impact of students' preferences and previous experiences on their Self-Regulated Learning decisions.

**Decisions based on assessment**, the third most prevalent category, involved students discussing using a studying strategy because of an assessment; students considered study strategies

Table 2 Categories of reasons for why students use specific studying strategies with representative quotes. Additional quotes are provided in the ESI. *Note:* ***Bolding*** *is used to focus the reader's attention, while* *underlining* *provides context and identifies the specific study strategy(s) discussed. The number of participants with shared ideas are noted by n values*

| Reason category | Example reason | Representative quote(s) |
|---|---|---|
| Decisions based on understanding/learning ($N$ = 16) | Seeking clarification | Minerva: *"So that way* ***I can understand certain topics*** *because some of them I understand right away but some of them I don't really understand so* ***I'll watch videos [online] so that way I can actually understand what I'm learning****."* |
| Decisions based on idiosyncratic/personal reasons ($N$ = 16) | Supports repetition/memorization & personal preference | Millicent: *"...I know that [writing/rewriting notes] down like on paper* ***helps you memorize it better than umm just typing it out*** *and...****I don't wanna like reference three things at once. So, I like to make my own like organized form of everything****."* |
| Decisions based on assessment ($n$ = 14) | Aligns with assessments | Hannah: *"Yeah [the instructor] has practice problems [from outside the textbook] ... I know that* ***they're gonna be very similar to what's on the exam****..."* |
| Decisions based on instructor ($n$ = 12) | Values resource because it is provided by the instructor | Charlie: *"[With the instructor's study guide]...I try to use all the resources that are provided to me...like* ***if they're created by an instructor for sure umm they're gonna have information that's useful to me****."* |
| Decisions based on reflection/metacognition ($n$ = 12) | Self-assessment | Charlie: *"[Teaching someone is] like if I'm going through everything that I know,* ***it's gonna be very obvious if I don't know something*** *and I'm trying to explain it cause sometimes* ***it's hard to know what you don't know****."* |



helpful for their assessment goals. These included strategies aligned with the assessment, such as Hannah discussing her use of practice problems that she considered similar to the exam (Table 2). **Decisions based on assessment** echo literature findings that assessments play a critical factor in student strategy choices and that exam performance influences future adaptations/choices (Boud, 1988; Kornell and Bjork, 2007; Jensen *et al.*, 2014; Harrison *et al.*, 2015; Stanton *et al.*, 2019; Nayyar *et al.*, 2024).

With assessments and instructional format being influential factors in selecting a study strategy, it is not surprising that most students described making **decisions based on the instructor** (Feldt and Ray, 1989; Entwistle and Entwistle, 2003; Kember *et al.*, 2008; Jensen *et al.*, 2014; Ewell *et al.*, 2023). Charlie (see Table 2) described the belief shared by many students that resources provided by the instructor are helpful for studying/learning. This contrasts with previous studies that found few students study the way they do because a teacher taught them to (Kornell and Bjork, 2007; Hartwig and Dunlosky, 2012; Morehead *et al.*, 2016; Fergus *et al.*, 2021); we found that students value instructor-provided resources and listen to what the instructor recommends.

**Decisions based on reflection/metacognition**, expressed by the fewest students, discussed ideas related to metacognition (*e.g.*, Charlie's use of self-assessment to monitor his learning in Table 2) and reflection (*e.g.*, prioritizing what to study in the future). **Decisions based on reflection/metacognition** commonly discussed ideas related to self-assessing themselves and were mentioned across all three types of strategies; this is a positive indication that students are aware of the metacognitive benefits of self-assessment, even if they are not using strategies tailored explicitly for it (*e.g.*, making a practice test) (Kornell *et al.*, 2009; Bjork and Bjork, 2014). Overall, these broad categories provide insights into how students consider the utility and effectiveness of studying strategies. To better explore these categories of reasons for using study strategies, we describe how students' reasons relate to each of the three overarching study strategy types, summarized in Fig. 5.

*Externally provided strategies.* The most common reason category for Externally Provided Strategies was **decisions based on assessment** ($n$ = 14, 88%); this idea was almost exclusive to Externally Provided Strategies, with only a few students mentioning it for other strategy types. The prevalence of **decisions based on assessment** being primarily for Externally Provided Strategies may lie in the origin of these strategies, as many are provided by the instructor (*e.g.*, instructor's notes and instructor's study guide or learning objectives). This can lead students to believe that the strategy aligns with the assessment and, therefore, perceive that it will effectively prepare them for an exam, especially when the strategy is recommended to be used by the instructor. For example, Rose described utilizing the instructor's practice problems as they align with what will be on the exam: *"[I use the instructor's practice problems] [be]cause I feel like from what I've seen in...the problems that he has on his problem set, it's kind of similar to the way it's structured on the exams and quizzes."* Rose sees a connection between the practice problems the instructor provides and the assessment, supporting the influence of assessments on students' studying choices (Nayyar *et al.*, 2024). This connection can cause students to value instructor recommendations or provided strategies, regardless of effectiveness, to achieve their desired performance goal. Promoting a mastery goal requires more focus on the individual and their unique needs, rather than a strong focus on assessments/performance.

**Decisions based on understanding/learning** was the second most common reason category for Externally Provided Strategies ($n$ = 13, 81%). These ideas focused on finding resources to supplement their education by watching videos online and/or seeking clarification on content they struggle with. This is not surprising given that these strategies are either directly provided to students and/or are readily accessible, representing less effortful ways to supplement classroom information. For example, Lily described using online videos to supplement her learning:

*I watch videos online because sometimes there are questions that I just do not know how to start...I used to watch them for stoichiometry...to just see the setup, the process so I could take*

 

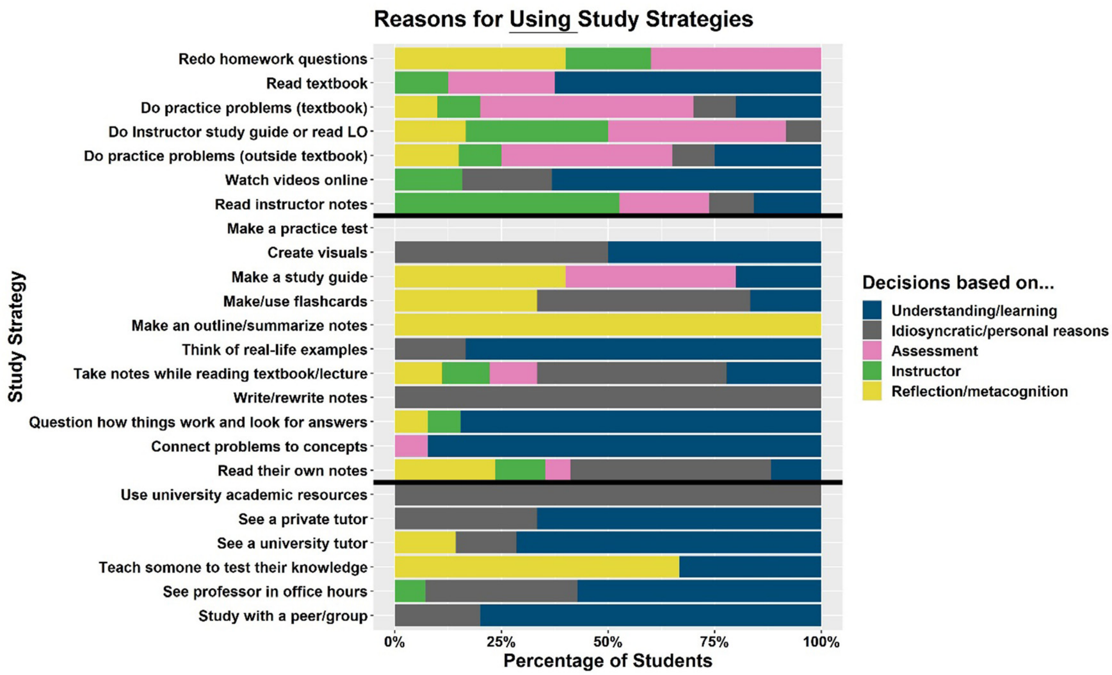


Fig. 5 Percentage of students using specific studying strategies by reason category. *Note: horizontal lines differentiate the three types of study strategies (consistent with* Fig. 4*). For each study strategy, different numbers of students make up each percentage, as some students shared multiple ideas across different reason categories*.

*their example, and I can input my own numbers and then calculate it and see if what I'm getting makes sense...*

Lily uses videos as a way to learn the material by using the examples provided to solve a similar problem in class.

The impact of the instructor on **decisions based on assessment** was further apparent with **decisions based on the instructor**, which was the third most common reason category for Externally Provided Strategies ($n$ = 12, 75%). With the instructor's direct influence on assessments, the unique ideas expressed by students were distinguished from the **decisions based on assessment** by the lack of explicit mention of an assessment and a focus on the instructor. Like the **decisions based on assessment**, **decisions based on the instructor** were mostly discussed for Externally Provided Strategies. As mentioned previously, many of the Externally Provided Strategies are often provided by the instructor, so, unsurprisingly, students value a strategy because the instructor provides the resource. Albert described using the instructor's study guide because the instructor provided it: ''*[The instructor's study guide/learning objectives is] just a good resource like I don't have to like search for if I can find something to like use to study*.'' Albert sees the instructor's study guide as an easily accessible resource that is helpful for his learning. Similar statements were made about the textbook associated with the course, where students recognized the value of additional resources recommended by the instructor.

Other instructor-based reasons, only expressed by a few students, include the instructor's resource being more simplified and straightforward, students valuing what the instructor emphasizes (*e.g.*, in their notes or learning objectives), and the instructor being an ''expert,'' so students value them and their recommendations. The influence of the instructor on students' selection of study strategies and materials indicates that instructors must seriously consider what study strategies they recommend or provide to students, as they are highly likely to be used. Previous literature has suggested that instructors should familiarize themselves with the effective study strategy literature to provide research-supported advice, particularly since instructors have recommended less effective strategies (Morehead *et al.*, 2016; Glogger-Frey *et al.*, 2018; Hunter and Lloyd, 2018; McCabe, 2018; Biwer *et al.*, 2020; Surma *et al.*, 2022; Ewell *et al.*, 2024).

**Decisions based on idiosyncratic/personal reasons** was the least common reason category for Externally Provided Strategies ($n$ = 7, 44%), where few students shared the same idea; the only idea in this category that multiple students shared was individualized/personal learning, mainly mentioned for watching online videos. For example, Lily discussed watching videos online because they are tailored to their audience: ''*I watch videos online...there is this one guy...he breaks [ideas] down so well. He gives you so many examples and...tries to make it such like a concrete fundamental thing for you to focus on and it brings it down...*'' Lily praises the video creator for designing and discussing the content at a level that is easier for students to understand. The importance of the resource being ''at their level'' was further discussed for Student Created and Social Learning Strategies, emphasizing the need to design resources for students by carefully considering their content knowledge, prior experiences, and vocabulary. Given that this category focuses on idiosyncratic reasons, it is unsurprising that many reasons were only expressed by one person; the ESI,† provides a complete codebook representing all the unique ideas/reasons elicited.

*Student created strategies.* Student created strategies were the second most common study strategy type used by students, and **decisions based on understanding/learning** ($n$ = 15, 94%) was the most common reason category for using these strategies. Specific reasons for using Student Created Strategies focused more on deeper learning ideas than the common help-seeking reasons for Externally Provided and Social Learning Strategies. The most common reason for using Student Created Strategies was that knowing connections helps understanding, which was primarily mentioned for study strategies that promote deeper learning (*e.g.*, asking questions about how things work and why, connecting practice problems to concepts). For example, Dean used real-life examples to make connections to what he was learning:

*If I'm working through a problem and I can't figure it out…I'll look online [for] like real life examples of this happening and…[when] given material you want to relate it to what you see on a daily basis, and it makes it easier to grasp…it makes you want to grasp it…*

Dean relates the content to real-life examples when he struggles to understand concepts, leading to a better understanding of the material and increased intrinsic motivation, also essential for student success (Ryan and Deci, 2000; Kuhbandner *et al.*, 2016). This focus on making connections to help understand content indicates that some students have an awareness of the need for deeper learning, even if the students themselves do not fully understand what deep learning is; this is reminiscent of an intervention study that found that some students only recognize principles of deep learning and its importance when formally instructed on it, even if they unknowingly can describe ideas related to deep learning (Gamby and Bauer, 2022).

The remaining reasons in this category varied, with few students sharing the same idea; however, three reasons shared a similar emphasis on deeper learning: wanting to understand why problems are solved certain ways, wanting to understand why the content is important, and knowing that chemistry is not just math so one needs to understand the concepts underlying the math problems. Albert discussed needing to connect practice problems to conceptual material because chemistry is not just doing math:

*[I connect practice problems to conceptual material] [be]cause I guess it just doesn't make it simply a math class you just ya'know if you know the chemistry behind it then I feel like you're all set and it just helps because I know I'm not simply doing math. I know why I have to do it…[and] what kind of math I need to apply to that problem to like get the right answer.*

Albert valued connecting practice problems to conceptual material, which aligns with content-driven study decision-making reported in the literature (Nayyar *et al.*, 2024). Albert's belief that chemistry is "more than just math" distinguishes him from students who identify chemistry as primarily mathematical. This distinction is further explored in why students do not use study strategies (research question 3).

The second most common reason category for Student Created Strategies was **decisions based on idiosyncratic/personal reasons** ($n$ = 15, 94%). Similar to Externally Provided Strategies, this reason category had few students sharing the same idea. The most prevalent reasons included that the strategy supported repetition/memorization, especially for inherently repetitive strategies (*e.g.*, rereading their notes, flashcards, rewriting their notes), and individualized/personal learning for strategies that students perceived to be "at their level" (*e.g.*, their own notes). Dean described using flashcards to memorize simple concepts: "*I would use flashcards for more memorization actually. I use them for the compounds or if I needed to remember oxidation numbers…I don't try to put too much work into the flashcards…*" Along with Dean, most students who shared this surface learning idea of memorization also discussed deeper learning ideas, particularly with **decisions based on understanding/learning** for Student Created Strategies. Although some students identified the need for deeper learning, they continued to use study strategies associated with surface learning.

Compared to Externally Provided Strategies, **decisions based on instructor** ($n$ = 3, 19%) and **assessment** ($n$ = 3, 19%) were less common for Student Created Strategies. This indicates that students may view Student Created Strategies as less connected to assessments, which may help explain the prevalence of students using Externally Provided Strategies over Student Created Strategies.

*Social learning strategies.* Similar to Student Created Strategies, the most common reason category for Social Learning Strategies was **decisions based on understanding/learning** ($N$ = 16, 100%); **decisions based on instructor** ($n$ = 1, 6%) and **assessment** ($n$ = 0) were not common. Of the variety of unique ideas discussed by students regarding Social Learning Strategies, help seeking for clarification and building understanding through teamwork were the most prevalent reasons. Seeking clarification descriptions were similar to those mentioned for Externally Provided Strategies, with the distinguishing factor being that students were seeking a human resource for help rather than a non-human resource. Seeking clarification was focused on one-way, help-seeking interactions as students sought help from another person. For example, Hermione discussed seeing a tutor for clarification:

*I feel like seeing my tutor is good cause if I have like a problem or if I don't know what I'm doing, she…help[s] me understand what went wrong cause I feel like sometimes with [the] professor, it's not as personal cause like it's a big lecture hall so it makes it better.*

Here, Hermione discusses social learning with a tutor to address her misunderstandings. At the same time, she admits that the professor is another resource; she describes the personal connection and individual interactions with the tutor as why she meets regularly with them over the professor.

Some students also expressed the idea of building understanding through teamwork, using two-way, help-seeking interactions where multiple individuals help each other. This two-way interaction was discussed for studying with a peer and teaching someone to test their knowledge. It is positive that introductory chemistry students recognize the benefit of peers for monitoring their understanding and gaining knowledge from other perspectives. This is contrary to a study in biology that found that only senior-level students understood the benefits of working with peers and learning from each other, while introductory biology students described working with peers to compare answers, not for learning or growth (Stanton *et al.*, 2019).

**Decisions based on idiosyncratic/personal reasons** was the second most common reason category for Social Learning Strategies ($n$ = 10, 63%). As seen with the other strategy types, this category had few students sharing the same idea; the most common reason across all three overarching types of study strategies was individualized/personal learning. Similar to the examples above, Charlie described studying with peers because they have a similar perspective:

*...[I study with peers because] there's a very good chance that if you don't know something somebody else does and they can explain it to you from like a student perspective too. And like chances are they've struggled on it too and they know how to get through it.''*

Not only does Charlie describe studying with peers to support his learning, but he further describes the importance of strategies being at the ''student's level,'' seen across all study strategy types and echoing findings that students consider user-friendliness when selecting help-seeking resources (Almaghaslah and Alsayari, 2022; Li *et al.*, 2023). Ruby mentioned another reason of note, as the only student who used the university's academic resources for academic coaching on time management and stress:

*I was having a hard time doing like time management. I know I met with [I] think [the University academic skills development coordinator who] help[ed] me plan out and think about how I can manage my academic umm stress and then I was also able to connect with someone to help me plan out my finals schedule which was helpful.*

Although Ruby was the only student to use the university's academic resources, she describes a positive experience with time and stress management support. It is concerning that this resource, while unique to the institutional context, is used minimally among the sampled students. This resource was purposefully created to address concerns about students' academic skills, yet the dissemination of the resources appears to be lacking. Additionally, a survey of various institution academic support centers found considerable variability in the study strategy recommendations among institutions, and recommendations may not always be evidence-supported strategies (McCabe, 2018). Academic resource centers should train those who consult with students to support them in their studies better. Further reasons students do not use this resource are explored below (research question 3).

*Impact of reflection/metacognition.* Students consistently discussed one reasoning category across all three overarching study strategy types: **decisions based on reflection/metacognition**. As such, rather than repetitively describing the idea in the above sections, we provide a holistic overview. The two main reflection reasons expressed by students were using self-assessment and prioritizing what to study. Self-assessing themselves was the most common metacognitive idea mentioned. Students have been previously found to underuse practice testing and rank it low in terms of effectiveness (Blasiman *et al.*, 2017); however, the use of self-assessment found in this study suggests that some students ($n$ = 9, 56%) recognize the benefits of self-assessment. The commonly used study strategies for self-assessment were either specifically for this purpose (*e.g.*, making a practice test and teaching someone to test your knowledge) or are readily adaptable for self-assessment (*e.g.*, flashcards and practice problems) (Bjork *et al.*, 2013). For example, Albert described teaching someone to test his knowledge as a form of self-assessment: ''*Like cause if you explain it to yourself that means you get it to like a...higher level than you [can by]...solving a problem. You can ask yourself why you did this...[and] you can like can apply it to other situations.*'' Albert directly discussed using these strategies to determine if he understood information, a reported benefit of metacognitive self-assessment (Kornell *et al.*, 2009; Bjork and Bjork, 2014). This indicates that some students know the metacognitive benefits of self-assessment, even if they use other study strategies instead of the desirably difficult creation of a practice test.

Another less prevalent form of reflection ($n$ = 6, 38%) was using Externally Provided and Student Created Strategies to prioritize what they should study. For example, Luna discussed outlining to focus on the content that she struggles with: ''*[I make an outline] because if I like to know the general idea and if I'm good with certain like sections of the chapter...then I'll just go focus on the ones that I'm struggling on.*'' Luna discusses reflecting on her understanding of the content when outlining to determine what content she should focus on. The reflections for self-assessment and prioritizing what to study are positive indications that students evaluate their learning while studying, a key tenet of Self-Regulated Learning (Zimmerman and Moylan, 2009).

Overall, when discussing their reasons for using study strategies, students provided numerous reasons; however, they primarily used learning/content as the cue for their decisions (see ESI,† for more details). Students expressed the importance of learning in their decisions through their reasons relating to help seeking and developing a deeper understanding of the content. However, the commonly used Externally Provided Strategies were often directly connected to assessments and the instructor, rather than their effectiveness for learning. Overall, these reasons provide insights into what drives student choices for studying. Although it is helpful to understand why students use strategies, it is more important to know why students do *not* use strategies to inform future interventions better.

### RQ3: What common reasons and cues do students have for not using studying approaches?

**Student reasons for not using studying strategies.** Similar to students' reasons for using specific studying strategies, *decisions based on assessment* and *decisions based on instructor* were also reasons students did *not* use specific studying strategies. However, four additional reasoning categories were identified that were unique for why students did *not* use specific studying strategies: **decisions based on not valuing the strategy**, **not knowing how to use the strategy**, **not needing the strategy**, and **the strategy not being available** (see Table 3 for exemplary quotations). The reason categories unique for not using study strategies were more prevalent than the reasons that overlap with why students do use specific study strategies (*i.e.*, the assessment and instructor categories). The most common reason categories for not using study strategies were **decisions based on not valuing the strategy**, **not knowing how to use the strategy**, and **not needing the strategy**.

**Decisions based on not valuing the strategy** had a wide range of unique ideas, connected by the common idea that the study strategy was not valuable. For example, see Neville's quote in Table 3, which suggests that making a practice test is not worth the effort required. There was quite a variety of these "not valuing" reasons identified in the sample, including some understanding/learning related ideas (*e.g.*, study strategy not being helpful to the way they learn, the strategy not working well for chemistry and student-created material may not be done well) as well as personal preferences (*e.g.*, preferring in-person/physical strategies and preferring peers over tutors and instructors). **Decisions based on not knowing how to use the strategy** described some lack of knowledge of the study strategy, whether it be the existence of the study strategy or how to use the strategy in chemistry, as discussed by Ruby in Table 3. **Decisions based on not needing the strategy** were focused on the strategy not being needed, such as Charlie not making a practice test because an instructor provided one, or he could find one online (see Table 3). While studying decisions are unique to the individual, all students discussed these three reason categories, supporting students' literature-reported lack of formal training on study strategies. This lack of training has been attributed to students not valuing desirably difficult strategies (*e.g.*, making practice tests) and students' inaccurate ratings of strategy effectiveness (Zimmerman, 1998; Kornell and Bjork, 2007; Bjork *et al.*, 2013). If students are not trained in the effectiveness or value of study strategies, it is not surprising that they believe they do not need certain strategies. More insights regarding students' not valuing strategies and lack of training are discussed below when the reasoning categories are connected to specific study strategies.

The last reason unique to why students were not using strategies was **decisions based on the strategy not being available** ($n$ = 8, 50%). **Decisions based on the strategy not being available** expressed a lack of access to specific study strategies, whether because the resource was not provided or students did not have the social connections to use that strategy. For example, Millicent (see Table 3) did not use an instructor's study guide because they are not provided. With many of the strategies being provided by external sources or requiring other humans to participate in social learning, it is understandable that for some of the students, these strategies were not available to them; students were enrolled in different sections taught by different instructors who provide different resources and suggestions, while also having differing social networks that influence the availability to use particular strategies (*e.g.*, social learning strategies).

The least common reason categories for not using study strategies were **decisions based on the assessment** ($n$ = 5, 31%) and **the instructor** ($n$ = 1, 6%), which happened to be the most common reasons why students did use specific study strategies. While only a small number of students discussed these ideas concerning not using studying strategies, it is clear that assessments and instructors significantly impact student studying decisions. This is not surprising, as the students emphasized the alignment of study strategies with exams in their reasons for using Externally Provided Strategies. Additionally, while only one student mentioned **decisions based on the instructor** for not using study strategies, they chose not to make an outline or take notes while reading the textbook because they valued what the instructor emphasized, instead of their own perceptions of what is important. What might be most telling is the lack of **decisions based on understanding/learning** regarding not using studying strategies; students have different perspectives regarding using or not using studying strategies, which is not surprising given that studying decisions are

Table 3 Categories of reasons for students not using specific studying strategies with exemplar quotes. Additional quotes are provided in the ESI. *Note:* ***Bolding*** *is used to focus reader's attention, while* underlining *is used to provide context and identify the specific study strategy(s) discussed. The number of participants with a response in that reason category is noted by n values*

| Reason category | Example reason | Representative quote(s) |
|---|---|---|
| Decisions based on not valuing the strategy ($N$ = 16) | Not worth the effort | *Neville: "[I do not make a practice test] [be]cause* ***I don't want to****…Because, I (pause) am lazy…****It's more time than I'm willing to put into it.****"* |
| Decisions based on not knowing how to use the strategy ($N$ = 16) | Do not know how | Ruby: *"I've* ***never [made flashcards] before so I don't how I would use it for chem.****"* |
| Decisions based on not needing the strategy ($N$ = 16) | Have alternative strategy instead | Charlie: "*[I do not] make a practice test* ***because I-I can find practice tests that are provided to me or can – I can find them online***." |
| Decisions based on strategy not available ($n$ = 8) | Resource not available | *Millicent*: "*I feel like* ***professors here don't make [instructor's study guides]****…my dinosaur [class] professor said…'that's something for high school' and left it at that.*" |
| Decisions based on assessment ($n$ = 5) | Alignment with assessments | Ruby: "*…I've look through some of the [practice problems from the textbook] and* ***it's like not worded like how my exam is****…*" |
| Decisions based on instructor ($n$ = 1) | Values what instructor emphasizes | Rowena: "*[I don't take notes while reading the textbook/lecture notesbecause] I just write like the notes like on top of like what [the instructor] already has cause* ***I don't wanna like focus on something else than what [the instructor] wants***." |

unique and contextual to the individual. Ideas about understanding/learning did come up as students described why they did not value specific strategies, such as students discussing study strategies that support memorization do not help with their understanding. The **decisions based on not valuing the strategy** category included other reasons that were not learning-focused (*e.g.*, not worth the money); therefore, it was presented as a separate category from decisions based on understanding and learning, focusing on the similar idea that the study strategy was not valuable. The use of understanding and learning in their decision-making was captured in the deductive cue analysis; the overlap between **decisions based on not valuing the strategy** and the deductive learning cue is discussed in the ESI.† To better explore these reason categories, we describe how they relate to each of the three overarching study strategy types, summarized in Fig. 6.

*Externally provided strategies.* With Externally Provided Strategies being more commonly used by students, fewer students shared similar reasons when describing why they did *not* use specific externally provided studying strategies; the most common reason category for Externally Provided Strategies was **decisions based on not valuing the strategy** ($n$ = 10). Like the reasons for using Externally Provided Strategies, the individualized/personal learning reason was also present for not using these strategies. However, in this case, the study strategy was perceived as *not* at the student's level; across all study strategies and reasons for not using them, individualized/personal learning was only discussed for Externally Provided Strategies (*e.g.*, homework questions and the textbook), despite crosscutting all strategy types as a rationale for using them. For example, Albert discussed why he does not value using a textbook:

*It was an option to get [a textbook] but I don't feel like it's worth the money...and especially they don't keep in mind that the people that are reading it don't know...the topic of what they're trying to like read about so they just use words that you don't feel like you know and people just tend to like read through them thinking they know what they're reading but majority of the times you don't.*

Here, Albert identifies the textbook as not being at his level, not helpful in improving his understanding, and not worth the money. He points out that textbooks not being at the student level can lead to students perceiving that they understand what they are reading when they do not. This is reminiscent of the feeling of familiarity that causes students to have a false sense of learning when rereading notes or textbooks (Koriat and Bjork, 2005; Kornell and Bjork, 2007; Dunlosky *et al.*, 2013; Blasiman *et al.*, 2017). This reasoning is also in line with intrinsic-value driven decision making presented in previous literature, where students choose strategies based on their emotions and the value associated with those strategies (Stanton *et al.*, 2019; Nayyar *et al.*, 2024), as opposed to effectiveness.

The second most common reason category was **decisions based on not needing the strategy** ($n$ = 9, 56%). One of these reasons concerns students having an alternative strategy that could be used instead. Most of these alternatives were other Externally Provided Strategies, including those provided by the instructor (*e.g.*, instructor's notes and the textbook). For example, Rose chose to use the instructor's notes rather than her textbook:

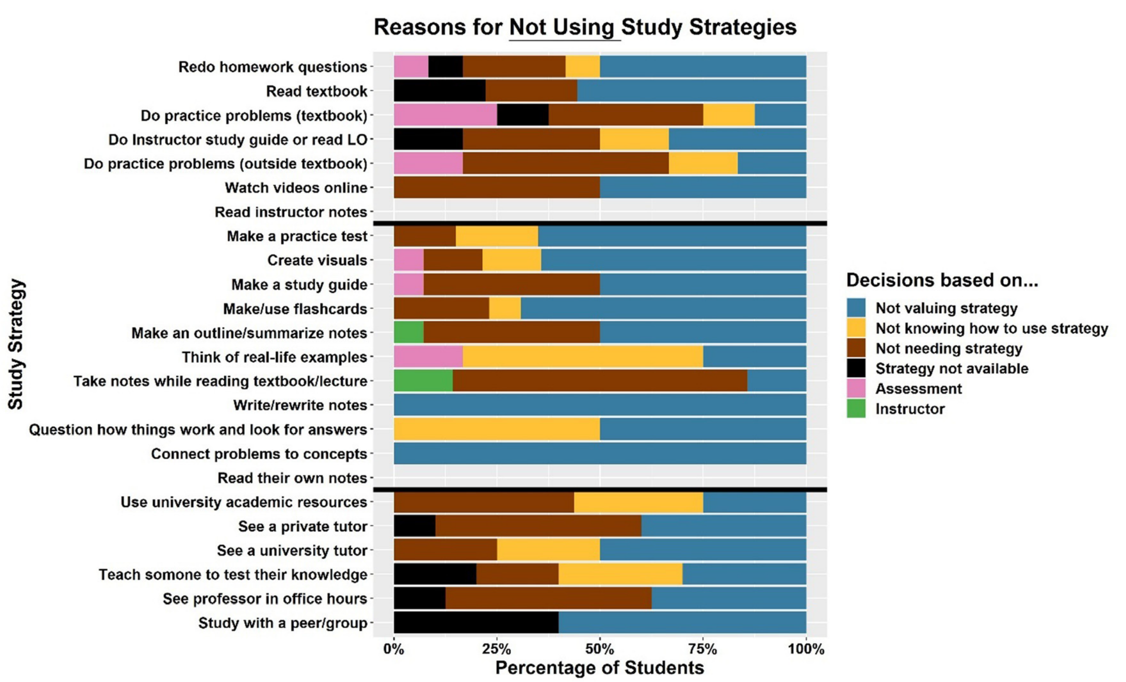


Fig. 6 Percentage of students not using specific studying strategies by reason category. *Note: horizontal lines are used to differentiate the three types of study strategies (consistent with* Fig. 4*) – Externally Provided Strategies on top, Student Created Strategies in the middle, and Social Learning Strategies at the bottom. For each study strategy, there is a different number of students that make the total of each percentage, and some students present multiple ideas from different reason categories and are counted more than once.*

"*I feel like [the instructor's notes] already has everything, and I just go into the textbook to see like the tables [the instructor] shows in class…like solubility rules…or like the strong bases and strong acids…*" When comparing study strategies, literature reports that students choose the strategy that requires less effort, echoed in Rose's selection of using the instructor's notes that already have a summary of everything she needs (Zeegers, 2001; Dye and Stanton, 2017; De Bruin *et al.*, 2023; Wang and Lajoie, 2023). With the students' unprompted comparisons of study strategies when asked about their decision-making approaches, future interventions should help students explicitly compare different study strategies and their effectiveness, particularly since students are naturally doing this regardless of their understanding of strategy effectiveness.

The category **decisions based on strategy not available** was discussed for Externally Provided Strategies ($n$ = 6, 38%), which is reasonable given that these strategies are provided to students and may not always be accessible or available depending on the individual instructor and/or section of the course (*e.g.*, instructor's study guide or learning objectives). For example, Millicent (see Table 3) discussed that college differs from high school, so instructors do not provide study guides (and therefore are unavailable for student use). A few students ($n$ = 4, 25%) mentioned **decisions based on not knowing how to use the strategy**, with no unique reasons shared by more than one student. With these strategies being provided to students, it is understandable that this reasoning category was not very prominent. However, those who did discuss this idea shared that they did not consider strategies, did not know about strategies, or lacked the expertise in the content to use the strategy. Overall, **not knowing how to use the strategy** was more prevalent for other study strategy types.

*Student created strategies.* With Student Created Strategies being less commonly used than Externally Provided Strategies, more students shared similar reasons for *not* using Student Created Strategies. The most common reason category was **decisions based on not valuing the strategy** ($N$ = 16, 100%). These reasons were focused on the time/effort required to use the strategy and the potential that student-created material may not be done well. Students who concentrated on time/effort perceived that the study strategy required too much time to make and was not worth the effort. For example, Dean recognized that creating a practice test was not worth the effort: "*No, I don't try to put too much work on myself…with the practice tests I don't try to put too much work on myself, because chemistry is already a large amount of work on yourself anyways.*" Dean does not value the effort required to make a practice test; such a lack of appreciation of effort is also reported in the literature, especially for more effortful strategies (*e.g.*, making a practice test, outline, or study guide) (Bjork and Bjork, 2014; Dye and Stanton, 2017; Stanton *et al.*, 2019; De Bruin *et al.*, 2023).

Another reason, besides effort, predominantly discussed for not making a practice test, was that student-created material may not be done well. This reason suggests that the material the student creates may be too easy, not good, and/or potentially inaccurate, compared to the resources provided to students. Rose provided an example about making a practice test that could be too easy or difficult, with no way to find out if she solved it correctly: "*I can't make [a practice test] of my own because I will just put easy questions, or really hard questions…and then I have no idea if I get it right or wrong then. Just leave it be, just [leave making a practice test] for someone else.*" Rose and other students' lack of knowledge on how to create their own assessment resources relates to the lack of formal training on effective study strategies reported in the literature (Zimmerman, 1998; Kornell and Bjork, 2007; Bjork *et al.*, 2013). Without explicit instruction on the role of effort and its impact on learning, it is unsurprising that students see effortful strategies as less valuable.

Along with needing explicit instruction on study strategies themselves, Self-Regulated Learning suggests that interventions must be context-related (Dignath *et al.*, 2008; Zimmerman and Moylan, 2009). Our data echoed this when students discussed why they **do not value a strategy**; some students believed that the resource does not work well for chemistry. For example, Rowena shared her belief that chemistry is more mathematical for why she does not make a study guide: "*[I do not use a study guide because]…for chemistry I think it's mostly on like math problems [than] like the concepts so then I kind of focus more on like solving problems than trying to memorize like every thing.*" Rowena described a content-driven decision (Nayyar *et al.*, 2024) as she believed that a study guide is not helpful for a chemistry context due to study guides being more conceptual, while chemistry focuses on solving math problems. Students discussed the importance (and prevalence) of understanding the mathematical aspects of chemistry, primarily when discussing reasons why they used specific strategies (*e.g.*, wanting to understand why problems are solved certain ways and wanting a model/example).

The second most common reason category for Student Created Strategies was **decisions based on not knowing how to use the strategy** ($n$ = 11, 69%). These reasons were more prevalent for Student Created Strategies than Externally Provided Strategies, which is not surprising given that Student Created Strategies (*e.g.*, making a practice test, creating visuals, and thinking of real-life examples) rely more on students' previous knowledge, awareness of the strategy, and how to create/make it. The reasons were generally that students had never considered the strategy before and did not know how to use the strategy (*e.g.*, thinking of real-life examples and making a practice test) while also having a context-specific reason for lacking expertise in the content (*e.g.*, thinking of real-life examples). For example, Lily discussed never considering a practice test before: "*Why don't [I] make a practice test? Honestly [be]cause I've never thought of it.*" The lack of consideration of making a practice test described by Lily may be related to students viewing practice testing as only for assessment purposes rather than for learning or studying; therefore, students may not consider it as a strategy when planning their studying in the forethought phase of Self-Regulated Learning, which influences the strategies used during the performance phase (Zimmerman and Moylan, 2009; Bjork and Bjork, 2014).

Millicent offers another perspective that focuses on her lack of expertise in chemistry: "*[I do not think of real-life examples because]...I just can't really think of chem[istry] on that level like I think of chem[istry] as something I just need to know...I think of it as numbers and it's hard for me to see numbers in the world...*" Millicent believes she does not have enough chemistry knowledge to think of real-life examples, which adds to the previous discussion of students believing chemistry is just mathematics. With students lacking knowledge in the content area and viewing chemistry as mathematics-based, this further supports literature suggestions that instructors should incorporate real-life examples directly in their instruction to help students make connections they may not make themselves (*e.g.*, Magwilang, 2016).

**Decisions based on not needing the strategy** ($n$ = 8, 50%) was the third most common reason for Student Created Strategies; the reasons were focused on students having an alternative strategy that could be used instead, like Externally Provided Strategies. When compared to the Student Created Strategies that were not used (*e.g.*, making a study guide and outline), the alternatives used by students were other, less effortful Student Created (*e.g.*, reading their own notes) and Externally Provided Strategies (*e.g.*, instructor study guide or practice test). For example, Charlie did not make his own study guide because they are usually provided to students: "*...study guides are provided for me usually. And I think that's just a little extra work that I don't want to do.*" The selection of the less effortful strategy was described by students in relation to Externally Provided Strategies, as well as in the literature (Zeegers, 2001; De Bruin *et al.*, 2023; Wang and Lajoie, 2023). Compared to the Externally Provided Strategies, **decisions based on strategy not available** was not mentioned for Student Created Strategies. This is reasonable given that Student Created Strategies require students to create them rather than being provided.

*Social learning strategies.* **Decisions based on not needing the strategy** ($n$ = 12, 75%) were the most common reason for Social Learning Strategies, sharing the reason for having an alternative strategy (*e.g.*, professor office hours and university resources) that was present for the other strategies. In the case of Social Learning Strategies, students' alternatives were "good enough," so students did not feel the need to use another strategy. For example, Neville saw a tutor and attended the professor's office hours rather than using any of the university resources: "*[I don't use the university resources] because the [personal/non-university] tutor and the [professor's] office hours are good enough for me.*" These alternative resources mentioned by students were mostly other Social learning Strategies (*e.g.*, seeing a Teaching Assistant) or were generic. These students believed that their strategies are good enough and/or require less time as reasons for not using an additional Social Learning Strategy.

In addition to alternative strategies, Social Learning Strategies included a unique reason: the resource was unnecessary because the student was doing well in class and was confident in their understanding (*e.g.*, personal tutor). For example, Minerva discussed that she was doing well in her chemistry class, so she does not need to see a tutor: "*I don't [see a tutor] just because I'm doing well in chemistry. So, I don't feel as though I need to.*" It is not surprising that students like Minerva would not seek help and use Social Learning Strategies if they were doing well in class, given the impact of reflection on self-determined learning and that students consider perceived effectiveness when choosing help-seeking resources (*e.g.*, Almaghaslah and Alsayari, 2022; Li *et al.*, 2023).

The second most common reason category for not using Social Learning Strategies was **decisions based on not valuing the strategy** ($n$ = 9, 56%). Like Student Created Strategies, there was a focus on time for why students did not value the strategy (*e.g.*, professor's office hours and university tutoring). The time-oriented reasonings described for Social Learning Strategies focused on the logistics of scheduling time in students' schedules to meet with someone else, rather than the time it took to make or use the strategy for Student Created Strategies. Millicent discussed that her professor's office hour schedule was not convenient: "*[I don't go to professor's office hours]...because sometimes they are not at the convenient times.*" These time-based ideas were present for all Social Learning Strategies that did not involve a peer, suggesting that peers are a quicker or less time-demanding resource. Luna explicitly stated this when discussing why she studies with peers instead of going to the professor: "*Because I do have friends who are more confident in chemistry. And umm if I'm struggling than they're advice is a lot helpful and they're...a quicker resource and it's faster than going to the professor*." The consideration of time efficiency is in line with time being a factor when students choose help-seeking strategies (Almaghaslah and Alsayari, 2022; Li *et al.*, 2023).

Another reason described for both Student Created and Social Learning Strategies was that the resource does not work well for chemistry. Albert shared the belief that chemistry is mostly mathematical, discussed with Student Created Strategies; however, he added to the idea by comparing chemistry to biology: "*I use [university tutoring] for biology...[which] is more concept based like there's a lot of stuff you need to know and how they connect with each other...you're pretty much asking [tutors] how to do math or something with chemistry*." Albert uses a tutor for biology and not chemistry, as he views biology as more conceptual; to Albert, tutors are less beneficial for chemistry because chemistry is focused on mathematics. This echoes previous literature in which students compared chemistry to biology and expressed that biology requires conceptual understanding while chemistry requires solving problems (Dye and Stanton, 2017).

The third most common reason category for Social Learning Strategies was **decisions based on not knowing how to use the strategy** ($n$ = 7, 44%). Like the other reason categories, students discussed never considering the strategy (*e.g.*, university resources and teaching someone to test their knowledge) and being unaware of the resource (*e.g.*, university resources). For example, Hermione was unaware that the university's academic and tutoring resources existed: "*I didn't really know [the university resources] were a thing to be honest with you*." As mentioned previously, the minimal use of university resources across the sample is concerning, and the lack of knowledge about the resources, especially those tailored to help with students' academic skills, needs to be addressed.

Like Externally Provided Strategies, the reason category **decisions based on strategy not available** was present for Social Learning Strategies ($n$ = 5, 31%), in line with strategy accessibility being a factor students consider (Almaghaslah and Alsayari, 2022; Li *et al.*, 2023). The students identified that they lacked a social network, preventing them from using these Social Learning Strategies (*e.g.*, studying with a peer or teaching someone to test their knowledge). For example, Ruby explains that she does not have someone she can teach to test her knowledge: *"[I don't teach someone because] I don't really have someone to do that with…"* Given that the sample is primarily comprised of first-year students, it is not surprising that many have had minimal opportunities to build their social networks/make friends with peers in their courses; helping students build these connections early in their collegiate careers (*e.g.*, at the beginning of a traditional semester) may be another fruitful way to help students succeed.

In contrast to the reasons for using study strategies, the reasons for *not* using study strategies relied on multiple cues, including learning/content, effort, and previous experience. Students used a combination of these ideas to determine if they valued or needed a strategy. For example, those not valuing a strategy may not see it as worth the effort, or those who do not believe they need a strategy may have an alternative strategy they can use instead. The cue of previous experience was predominantly mentioned when students discussed a lack of experience with the strategy, echoing our students' lack of formal training. More specifics about these ideas are shared in the ESI.†

# Conclusion

With the lack of formal training described by students, echoed in the literature (Zimmerman, 1998; Kornell and Bjork, 2007; Bjork *et al.*, 2013), it is not surprising that student decisions were not informed by how effective study strategies are; instead, they were informed by student beliefs. Fig. 7 provides a concise summary highlighting the most common reasons for each type of strategy. Overall, students relied predominantly on Externally Provided Strategies and less effortful Student Created Strategies, in line with previous quantitative research findings (Zeegers, 2001; De Bruin *et al.*, 2023; Wang and Lajoie, 2023).

The use of at least one Social Learning Strategy by every student for help-seeking purposes contrasts with previous work that suggested students do not always seek help when needed (Won *et al.*, 2021). When selecting strategies, students relied on cues focused chiefly on perceptions of how much they learn or how helpful a strategy is for the content. The reliance on this cue was connected to **decisions based on understanding/learning** being the most common reason category discussed by students. For Externally Provided and Social Learning Strategies, **decisions based on understanding/learning** ideas were for supplementing their learning and help seeking. At the same time, those using Student Created Strategies described deeper learning goals to understand the material better. For example,

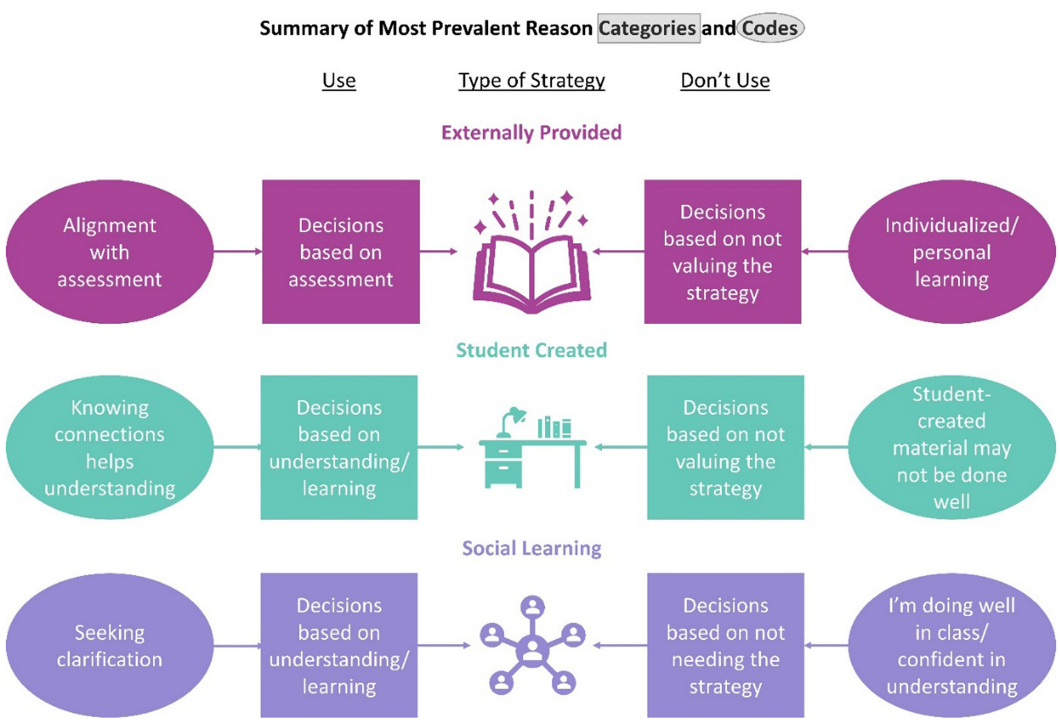


Fig. 7 Summary of the most prevalent reason categories and codes by strategy type.

 

one student described connecting practice problems to the content because chemistry is not just about being able to do math. The assessment and instructor also played an essential role in choosing Externally Provided Strategies. While the assessment and instructor impact have been found in previous literature as factors for student decision making (Feldt and Ray, 1989; Entwistle and Entwistle, 2003; Kember *et al.*, 2008; Jensen *et al.*, 2014; Ewell *et al.*, 2023), the influence of the instructor found within this sample contrasts previous studies that found few students study the way they do because a teacher taught them to (Kornell and Bjork, 2007; Hartwig and Dunlosky, 2012; Morehead *et al.*, 2016; Fergus *et al.*, 2021). This influence emphasizes the need for instructors to undergo study strategy training (Morehead *et al.*, 2016; Glogger-Frey *et al.*, 2018; Hunter and Lloyd, 2018; McCabe, 2018; Biwer *et al.*, 2020).

Reasons for not using study strategies relied on multiple cues of learning/content, effort, and previous experience. All students discussed reasons related to **not valuing the strategy**, **not knowing how to use the strategy**, and **not needing the strategy**, relating to the lack of formal training in the literature (Zimmerman, 1998; Kornell and Bjork, 2007; Bjork *et al.*, 2013) and described by participants. When considering not valuing strategies, students believed that some resources would not work well for chemistry, often because they believed chemistry is mostly mathematically based. For example, one student used university tutoring for biology rather than chemistry because they believed biology required a more conceptual understanding. Along with the relation of the strategy to the subject, students also considered their ability to use or make the strategy; they believed that some of their created material might not be done well. For example, a practice test made by a student may be too easy, not good, and/or potentially inaccurate. There were also strategies students were unaware of or never considered using when studying, such as the university's academic resources and making a practice test. In contrast, other strategies were seen as alternatives (*e.g.*, instructor-provided practice problems or study guides) that led students to believe they did not need to use more effortful strategies. These reasons suggest that students need to be made aware of effective strategies and convinced to value them over less effortful or effective strategies.

## Implications

This study has multiple implications for teaching/learning environments and future research. The importance of assessments and instructors in choosing Externally Provided Strategies has important instructional implications. While the assessment and instructional format are factors in student decision-making (Feldt and Ray, 1989; Entwistle and Entwistle, 2003; Kember *et al.*, 2008; Jensen *et al.*, 2014; Ewell *et al.*, 2023), the influence of the instructor discussed with our student sample contrasts previous studies that found few students study the way they do because of teacher suggestions (Kornell and Bjork, 2007; Hartwig and Dunlosky, 2012; Morehead *et al.*, 2016; Fergus *et al.*, 2021). The discussion with our students suggests that instructors must seriously consider what study strategies they recommend or provide to students, as they are likely to be used. This influence also emphasizes the need for instructors to familiarize themselves with the effective study strategy literature to provide research-supported advice and have metacognition and study strategy training, particularly since instructors have recommended ineffective strategies (Morehead *et al.*, 2016; Glogger-Frey *et al.*, 2018; Hunter and Lloyd, 2018; McCabe, 2018; Biwer *et al.*, 2020; Surma *et al.*, 2022; Muteti *et al.*, 2023; Ewell *et al.*, 2024). Previous literature also recommends that instructors should incorporate more effective study strategy recommendations in their syllabus and include explanations on how to use academic help-seeking instead of listing resources (*e.g.*, some students are unfamiliar with what is expected for office hours) (Ewell *et al.*, 2024). Instructors are also recommended to tailor course resources to promote effective learning strategies (*e.g.*, do not provide solutions to students to facilitate meaningful self-assessment) and incorporate activities that model using effective study strategies in review sessions (Laguerre Van Sickle and Frey, 2025).

Students shared the belief that chemistry is more of a math-based course, leading them to choose strategies based on mathematical learning over conceptual learning. This mathematical perception of chemistry emphasizes the need to reconsider the way introductory chemistry content is taught to students; for example, the over-emphasis of stoichiometry in introductory chemistry should be reconsidered as students reportedly focus on memorizing algorithms to solve math problems in a chemistry context, rather than applying chemistry to consider problems encountered by scientists (Rosa *et al.*, 2022). The overemphasis of rote mathematics has also been suggested to increase chemistry student educational inequity (Ralph *et al.*, 2022). Promoting a more conceptual understanding approach with students can involve focusing on problem-solving processes, student reasoning, and incorporating crosscutting concepts and systems thinking (Bunce, 2001; National Research Council, 2012; Talanquer and Szozda, 2024). Additionally, instructors should decrease the prevalence of summative, high-stakes assessments in the curriculum due to the significant influence of the assessment on students' studying choices, further echoing suggestions from previous literature (French *et al.*, 2023). Such a focus on the exam/assessment by students is a performance goal orientation rather than a mastery goal orientation, which is not the recommended mindset for student success and learning (Pintrich, 1999; Muis, 2007; Naibert *et al.*, 2024). For example, focusing on exam performance could include learning content solely for the exam and not seeing exam feedback as needed or useful for future learning (Sambell *et al.*, 1997; Harrison *et al.*, 2015).

Chemistry is an abstract and highly visual field; however, students viewed chemistry as mathematics-based and described not knowing how to, or not valuing, thinking of real-life examples or creating visuals to understand chemistry concepts. With students describing their inability to think of real-life examples, instructors should incorporate real-life examples directly to help students make these connections. Using context-based learning has improved student achievement in chemistry, their motivation to learn chemistry, and their attitude towards their course (Vaino *et al.*, 2012; Magwilang, 2016). Research has also suggested that conceptual teaching (*e.g.*, using particle visualizations) rather than algorithmic teaching leads to deeper and more long-term learning (*e.g.*, Gabel, 1993; Yezierski and Birk, 2006; Salta and Tzougraki, 2011; Bridle and Yezierski, 2012; Taber, 2013). Research into incorporating molecular animations into teaching shows an increase in student understanding, and students have identified the use of animations as helpful to their understanding of concepts throughout their degree program (Williamson and Abraham, 1995; Tasker and Dalton, 2006; Yezierski and Birk, 2006). Supporting students making connections among multiple graphical representations has also improved student learning (Rau, 2015). With previous research supporting the use of visualizations to improve student learning, the lack of students creating their own visuals or not valuing the use of visuals when studying emphasizes the need to incorporate more visualizations into classroom instruction; there should also be examples on how to create their own visuals. This follows suggestions that instructors model how to operate between more than one domain of Johnstone's triangle (Johnstone, 1991; Taber, 2013; Gkitzia *et al.*, 2020). With the importance of the assessment of students' study choices, assessments should also include visuals (*e.g.*, particle pictures, models) to influence students to consider visualizations as necessary for learning chemistry.

The variety of reasons behind student choices supports the suggestion that a "one-size-fits-all" intervention would not benefit all students (Nayyar *et al.*, 2024). The literature on intervention studies has found that not all interventions successfully improve student study strategy choices and metacognition, suggesting that only focusing on providing knowledge of effective study strategies is not enough to cause students to change (Stanton *et al.*, 2015; McDaniel and Einstein, 2020; Muteti *et al.*, 2023). This has led to discussions about addressing the barriers students perceive that stop them from selecting effective strategies when developing interventions (Wang *et al.*, 2023). The influence of effort on student decisions, reported in the literature (Zeegers, 2001; Dye and Stanton, 2017; De Bruin *et al.*, 2023; Wang and Lajoie, 2023; Wang *et al.*, 2023) and described by our participants, support that study strategy instruction must address the effort barrier; this includes focusing on the benefits of desirably difficult strategies and explaining why they are "worth the effort" and the learning benefits. Also, study strategy instruction should focus on helping students improve their Self-Regulated Learning, while being context-specific, to address the strategies that students may not view as helpful for the content/discipline, particularly given that our students often mentioned effective strategies were not valuable for chemistry. Additionally, some students need further instruction on how to use the metacognitive skills that interventions have been designed to teach them and need continuous coaching on metacognitive regulation and knowledge to have long-term impacts (Stanton *et al.*, 2015; Muteti *et al.*, 2023; Laguerre Van Sickle and Frey, 2025). For example, metacognitive classroom activities can help students maintain exposure to metacognition regulation and knowledge (Muteti *et al.*, 2023). Future research should investigate students' perspectives on interventions and try to include students' voices and language in intervention designs. This qualitative study provides multiple inductive reasoning categories and unique student reasons (see ESI†) that can inform chemistry-specific interventions, allowing for contextualized and student-informed insights.

With students spontaneously comparing strategies in their reasonings, study strategy instruction should help students compare strategies to understand why some are more effective than others. Future research should go more in-depth to compare strategies against each other and elicit the reasons and cues for why students would choose one over another. With the lack of formal training on studying/learning, as well as the reports that students often do not need effective strategies to succeed during their K-12 education (*e.g.*, McGuire, 2006; Dye and Stanton, 2017; Ewell *et al.*, 2023), there is a need for investigations that focus on when it is most beneficial in students' academic careers to implement such training. Previous literature has suggested starting metacognition instruction in K-12 education settings and including opportunities for metacognition instruction in college freshman seminars and bridge courses (Muteti *et al.*, 2023). For example, one study with a middle school physics class used scaffolded self-regulated learning instruction assignments that started as content-light puzzles before moving to content-rich physics problems. The students randomly assigned the metacognition assignments performed better when tested on their conceptual physics knowledge than those who only did traditional physics practice problems (Zepeda *et al.*, 2015). With the findings that metacognition continues to develop into adulthood and metacognitive ability reaches a plateau with age, research focusing on the use of interventions at different educational stages is also needed to understand the most effective time (Weil *et al.*, 2013; Zepeda *et al.*, 2015).

## Limitations

While these findings provide important implications for student studying habits, discussing the study's limitations is essential. Although the data collected from the 16 participants evidenced data saturation (Patton, 2002), additional participants could help diversify the sample, as some demographics had minimal representation. While it makes sense that we found no patterns/trends based on gender identity, ethnicity identity, or major given the unique and personal nature of studying decisions, it is possible that this lack of finding stems from the sample size. Despite evidence for data saturation, there may have been unique ideas missed by not including additional participants; however, placing individual reasons into categories minimizes the impact, as the reason categories already encompass many reasons described by participants. Additionally, overarching ideas provide insights that support transferability to other contexts. Also, various majors were represented in the sample, which may make the findings transferable to similar contexts with various majors in the course. Additionally, the exam and course grades for participants were not collected. This prevents determining study strategy patterns in usage, reason, or cues based on achievement groups. However, quantitative surveys about deep and surface learning have examined the connection between the achievement group and the study strategy approach. Our study focused on the reasons behind their choices, not how they relate to their grades. Lastly, two study strategies were specific to our institution's context (use university academic resources and see a university tutor); therefore, the implications of those resources do not necessarily transfer to other institutions. However, institutions that have study strategy support and tutoring resources may benefit from the findings regarding those resources.

## Author contributions

The first and last authors conceptualized and designed the project. The first author conducted all interviews. All four authors participated in data analysis and discussions. The first and last authors drafted the manuscript, and all authors read and approved the final manuscript.

## Ethical considerations

This study was conducted with approval from the Institutional Review Board of the University of Rhode Island (Reference Number: 1955297), and all students consented to participate.

## Data availability

Raw data are not publicly available, as participants in this study did not consent to their data being shared publicly, and approval for this study did not include permission for sharing data publicly. However, a complete codebook for all inductive student reasons is included in the ESI,† along with representative quotes beyond those presented within the manuscript.

## Conflicts of interest

There are no conflicts to declare.

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