Epistemological Framing of Chemistry Assessment Items

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Abstract: This study explores undergraduate chemistry students' epistemic frames for stoichiometry assessment items. We interviewed 40 introductory chemistry students to understand their experiences of a selection of items which were presented as pairs containing one traditional format item, typical of what is used in their undergraduate course, and a revised form, modified following principles of the Equitable Framework for Classroom Assessment (Siegel, 2007). Our analysis suggests that how the item is presented (i.e., as an exam or homework item) is very important to students' epistemic frame and goals. We found that students perceive efficiency (of time) as one key affordance of conceptual problems. Finally, students are cognizant of differences in problems that elicit understanding of concepts rather than mere mathematical manipulation and place substantial value on the former. Our study is a step towards forms of items that support learning aims and assessment aims as joint goals.

Introduction

Chemistry educators have noted discrepancies between students' performance in traditional, calculation-based problems and conceptual problems (Nurrenbern & Pickering, 1987). One of the challenges with assessment items is that instructors and learners view them as means to evaluate what students know (Shar et al., 2020), not as contexts for learning or making sense of entities and their relationships, often by applying a known procedure to calculate an answer to a problem, a process that Chen and colleagues (2013) deemed "answer-making." In contrast, science education literature increasingly highlights the role of sensemaking in science learning, which refers to learners' effortful work to "figure something out" (Odden & Russ, 2019a, p. 191) by drawing on what they know, often including a mix of everyday and academic knowledge (Odden & Russ, 2019b). Hunter and colleagues (2021) describe sensemaking in a chemistry context as learners' process of "recognizing a gap in knowledge and working to construct an explanation that resolves this gap" (p. 328).

We desire chemistry assessments to be useful contexts for students' learning, not mere evaluation of knowledge. This calls for a shift in the epistemic game (e.g., Chen et al., 2013) of chemistry assessment, including finding ways for students to reimagine the rules and expectations of problem-solving practices. Drawing on earlier work on epistemological frames (Scherr & Hammer, 2009; Shar et al., 2020) which are "tacit stances that students take toward learning-based activities" (Shar et al., 2020, p. 3), this study examines the epistemological frames that students adopt in response to stoichiometry problems. As argued by Hammer et al., 2005, epistemological frames are students' underlying (and typically unspoken) answer to the question, "How should I approach knowledge?" (Hammer et al., 2005, p. 12). Learners' frames for assessment items shape their decision-making about what is productive and worthwhile within a particular activity. Thus, in this study, we investigate the nature of epistemological frames that undergraduate chemistry students employ when approaching stoichiometry assessment items. We ask: What is the nature of undergraduate chemistry students' epistemological frames for stoichiometry assessment items?

Context and methods

The participants of the study are 40 undergraduate students, each of whom was enrolled in an introductory chemistry course at a large research university in the northeastern United States. We conducted 1-hour, semi-structured interviews with all participants concerning stoichiometry assessment items. The intended purpose of the interviews was to investigate how the language and format of chemistry assessment items can become more accessible for students. During the interview, students were presented with two or three pairs of stoichiometry assessment items, as shown in Table 1. The pairs of items include instructors' original version of a stoichiometry assessment item and a revised version of the item, modified following principles of the Equitable Framework for Classroom Assessment (Siegel, 2007). Students were presented with the problems and asked to explain how they approached and solved them. The students then gave feedback to the interviewer on which parts of the items were helpful and challenging, and what they liked or disliked about the problems.

The first author coded the transcripts using methods of interpretive phenomenological analysis (Smith et al., 2009). Initial themes described students' experience of the item pairs. We then generated superordinate themes, specifically related to students' framing of the problem. To illustrate the themes, we draw on four focal undergraduate students who were selected because their responses helped to explain features of the broader theme. Participants 7 and 22 attend a large, research-intensive campus, whereas Participants 23 and 26 attend a smaller campus of the same institution. Each participant is in their first year of study. Of these students, one identifies as female and three as male. The selected interview excerpts exemplify the character of the broader themes of the interview data.

Table 1
Sample Original and Revised Item Text

	Assessment Item Text
Item A Original	In the following chemical reaction between H_2 and Cl_2 to produce HCl, what is the sum of the mass of HCl produced plus the mass of left-over reactants when 0.36 g of H_2 completely reacts with 12.42 g of Cl_2? $H_2 (g) + Cl_2 (g) \rightarrow 2HCl(g)$
Item A Revised	Hydrogen gas (H_2) and chlorine gas (Cl_2) react in a container to produce hydrochloric acid (HCl) in the reaction below: $H_2 (g)$ + $Cl_2 (g)$ → 2HCl (g) Initial Amount X Y At the start of this reaction, there are X grams of H_2 and Y grams of Cl_2. After the reaction is complete, what is the **total** mass in the container? Choose the best option. a) X + Y b) X + Y + 2XY c) 2 XY d) 2(X + Y)
Item B Original	Calculate the number of moles of nitrogen dioxide, NO_2, that could be prepared from 0.35 mol of nitrogen oxide and 0.25 mol of oxygen. $2NO(g) + O_2(g) \rightarrow 2 NO_2(g)$ Identify the limiting reagent and the excess reagent in the reaction. What would happen to the potential yield of NO_2 if the amount of NO were increased? What if the amount of O_2 were increased?
Item B Revised	In this reaction, 0.35 moles of NH_3 and 0.25 moles of HCl are used to produce NH_4Cl. NH_3 + HCl → NH_4Cl Initial Amount 0.35 mol 0.25 mol a) The limiting reactant is ________________. b) The excess reactant is _________________. c) If the amount of NH_3 were increased, would the amount of NH_4Cl also increase? Why or why not? d) If the amount of HCl were increased, would the amount of NH_4Cl also increase? Why or why not?

Themes

1. Accounting for the time constraints of the assessment environment

The epistemic frame underlying assessment items is often regarded as "answer-making" (Chen et al., 2013; Hunter et al, 2021). In our study, students were presented with two versions of an introductory stoichiometry problem (Table 1, Item A). The original item is adapted from Blackman et al. (2018). While students were familiar with the original version (a procedure they had seen in class), some expressed preference for the conceptual nature of the revised version. For example, Participant 26 highlights the revised item as a more efficient way to demonstrate conceptual understanding without extensive calculations and indicates a preference for the revised, more conceptual version. Their feedback suggests a general desire for conceptual qualities of chemistry assessment items as an efficient use of limited time.

> The fact that there were no numbers given here [Item A-Revised], it was just variables… I know obviously you need to have numbers in some of [the items] cause, you know, that's chemistry, but I did

like [the revised item] a lot just because of how I work. It's just not as many factors going into my thought process, especially in a class where I have 50 minutes…I feel like I do better when I have more time to do things and like with this one I could figure this one out in a pretty quick amount of time.

Similarly, Participant 23 also appreciated the absence of numerical values in the revised item:

If I'd never seen either of these before I would probably pick [the original version], just because I'm comfortable with that but, I definitely would be interested in seeing a question like [the revised version] because I feel like it'd be a good way to try to display concepts without taking up too much time of that sometimes we have really long questions on an exam and it's trying to figure out how much time we're going to spend on each question… With [the revised version] you can still show that you can learn the concept that you know what you're doing well [and] also not having to pull a calculator out and periodic tables and all that stuff.

Preference for conceptual problems was not uniform across all participants nor across all items. However, prior literature suggests that students do better and prefer items that rely on known procedures, rather than broader conceptual work (Nurrenbern & Pickering, 1987). P23 and P26's responses suggest, rather, that reducing numerical and procedural manipulations is beneficial under the pressure of a time-limited assessment. This view still prioritizes an answer-making approach (rather than sensemaking) but accounts for conceptual relationships as a way to overcome time constraints of the assessment environment by avoiding numerical calculations.

In addition to students' view that conceptual problems may be more efficient, their perspectives about supplemental information within the assessment items depended on the context and was an affordance in "practice" items. Supplemental information is sometimes included to help students see the relevance of chemical concepts in everyday life and historical contexts, perhaps fostering deeper engagement with the material. In our study, participants confirmed that supplemental information may in fact be interesting. One of the original format assessment items begins with an introduction to phosgenite, "Phosgenite, a lead compound with the formula $Pb_2Cl_2CO_3$ is found in ancient Egyptian cosmetics. Phosgenite was prepared by the reaction of PbO, NaCl, H_2O, and CO_2…"(Gilbert et al., 2018, p.139). P7 indicated that contextual information adds interest to items used in practice sessions, "I feel like that would be nice to know in like a practice format because I do think that's kind of cool how they tell us.. like what it is." This perhaps reflects P7's appreciation for the broader context and real-world application of chemistry concepts.

However, several students, including P7, noted that such information was a perceived weakness of assessment items. P7 argued that during a test, it "would just be distracting." P7 elaborated by considering multilingual peers, highlighting that the additional information could add to the complexity of understanding the question, impeding performance under time constraints: "If I was someone who, English was a second language or [someone who is] a little slower with comprehending the words at all, that fluff is just like unnecessary." For P7 at least, supplemental and contextual information (i.e., "fluff") plays different roles in their in different environments: in one context, it adds interest, yet in an assessment context, it may have an uneven and inequitable impact to student performance.

2. Acknowledging differences between procedural and conceptual engagement

We also found that participants were self-aware of the differences between their own procedural and conceptual engagement. While all students recognized that calculation and mathematical components are included in chemistry items, students often saw those parts as rote memorization or even obstacles to answer-making (Theme 1). While the original Item B (Table 1, Spencer et al., 2006, p. 61) and revised items include similar conceptual questions below a chemical equation, the conceptual questions were more noticeable in the revised version due to formatting differences, including increased white space which is not displayed in Table 1 due to limited space in this manuscript. Participant 22 acknowledged the usefulness of conceptual problems in the revised item:

I was thinking actually with [questions] C and D that those are actually like…I think those are good questions for the conceptualization, because just memorizing how to do the math is different than actually understanding like what the math is telling you basically, and so having like C and D there I think really help check for like actual understanding of the material.

P22 emphasizes the importance of understanding the conceptual basis of mathematical problems in chemistry rather than just "memorizing" the procedures. While P22's response is still focused on demonstrating their understanding (i.e., answer-making), P22 acknowledged the value of conceptually-oriented questions, naming the importance of "understanding [like] what the math is telling you." We characterize this as problem solving (not sensemaking), but view this as a step toward a sensemaking frame, which is characterized by deeper explanation and gap-filling. Furthermore, P22 highlighted that certain types of questions ("like C and D") are effective in assessing "actual understanding" of the material rather than just the ability to perform calculations. The difference in the way P22 approached the original and revised items also indicates that the presentation of assessment items influenced P22's framing of the problem as more conceptual, suggesting that the presentation (e.g., spacing and enumeration of sub-questions) is perhaps as important as the content of the item.

Discussion and Conclusion

Nurrenbern and Pickering (1987) demonstrated that students find conceptual problems more challenging than procedural problems. However, our study describes students' perceptions of affordances of conceptually-oriented assessment items as a more efficient use of time during test-taking and useful for "actual understanding." Our paper adds to the literature on epistemological framing, noting the importance of context in how students approach items. Students are cognizant of fundamental differences between (1) producing answers via known procedures and numerical manipulation and (2) demonstrating understanding of underlying, fundamental concepts. Additionally, students find supplemental information (e.g., that phosgenite was used in ancient cosmetics) beneficial for interest, but note that supplemental information may have an uneven and inequitable impact across test-takers, especially under time constraints. Existing literature on sensemaking has traditionally focused on peer discussions rather than assessment contexts (e.g., Hunter et al., 2021; Odden & Russ, 2019b), and our work demonstrates how stoichiometric assessment items can promote reasoning about concepts, potentially moving toward the feasibility of sensemaking in assessment items in general chemistry courses. Overall, the themes push back on the *evaluation-only* nature of assessments in undergraduate chemistry and call us to reimagine what forms of items can best support learning aims and assessment aims as joint goals.

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