Managing intuition in collaborative problem solving: a case study of beyond-intro chemistry and physics students

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Intuition has been reported as being pivotal in guiding students' problem solving. In this ongoing project, we employ a grounded approach to investigate how students use intuition during problem solving in beyond-intro chemistry and physics courses. We adopt a dynamic perspective on intuition, recognizing its context-dependency, to examine how students respond to their intuitions. In a case study, we inductively analyze existing video data of problem-solving sessions, and show that students' responses to intuition can be productive or unproductive, regardless of the intuition's appropriateness. This highlights the need to equip students with strategies to manage their intuitions productively. Based on our findings, we recommend teachers to: adopt a flexible stance toward intuition; explicitly incorporate the topic of intuition in classroom discussions; and encourage students to actively reflect on their intuitions. Future studies should consider the processes governing the development of intuition and expand research on students' epistemological views on intuition.

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I. INTRODUCTION

"Should we just throw out, like, our intuition and then check?" (Cole, upper-division physics student)

Intuition, serving as a mechanism to reduce cognitive load and aid in rapid interpretation of one's surroundings, has been the subject of inquiry across various disciplines, including philosophy, psychology, and research on decision-making in healthcare and business (e.g., [1, 2]). The extensive study of intuition across diverse fields, coupled with its vague nature, has yielded a myriad of perspectives regarding its essence and who may, or may not, possess it.

While an exhaustive review of the literature on intuition exceeds the scope of this brief paper, we acknowledge the breadth of perspectives it entails. These perspectives range from regarding intuitive actions as characteristic of expert behavior—asserting that experts simply do what normally works rather than actively make decisions [3]—to considering intuition primarily as a trait of novices, contrasting reliance on intuition with the rationality observed in experts' actions [4].

In physics education research (PER), the study of intuition has been approached from various angles. Corsiglia *et al.* [5] present four major research strands: intuition as *barriers* to understanding or problem solving; intuition as an *instructional goal*; the *ontology* of intuition, aiming to define and understand intuition; and the *epistemology* of intuition, where the main focus has been to explore experts' views on intuition. Within the realm of chemistry education research (CER), the study of intuition has predominantly centered on students' use of heuristics (e.g., [6–8]). More specifically, how students' heuristics, also referred to as intuitive judgments or implicit assumptions, impact their decision-making in ranking and multiple-choice tasks aimed at enhancing students' conceptual understanding in chemistry. There has been comparatively less emphasis on examining the role of intuition in more complex or novel problem-solving scenarios. Given its apparent and inevitable influence on students' problem-solving approaches, further investigations into intuition and its role in such contexts are warranted. This notion is mirrored in the diverse body of educational research dedicated to exploring the topic.

Before introducing our research question, we wish to clarify that the aim of this paper is not to redefine intuition. Rather, we adopt a flexible perspective on intuition that draws inspiration from existing ideas. Following Brady *et al.* [9], we consider intuition as the manifestation of one's tacit knowledge, triggered by rapid interpretation of one's surroundings and influenced by one's beliefs and values. This understanding resonates with the resources framework, which conceptualizes knowledge as dynamic networks of small cognitive units, resources, activated differently depending on context [10]. Within this framework, resources are not classified as "right or wrong"; instead, their activation is deemed productive or unproductive within a given context. Similarly, we challenge the notion that intuition is static or exclusive to either experts or novices; on the contrary, we view it as a dynamic trait that can evolve over time through practice and experience. Such perspective is echoed by e.g., Sherin [11] and Kryjevskaia *et al.* [12].

The opening quote illustrates a key finding from our previous work: that students frequently turn to their intuitions to navigate problem solving. Therefore, we believe that it is important to consider how students manage their intuitions regardless of the perspective on intuition that researchers and teachers adopt.

This work is part of an ongoing collaboration between scholars in CER and PER. Seeking to extend the scope of research within our respective fields into more advanced level topics, our overarching goal is to explore how students enrolled in beyond-intro level physics and chemistry courses navigate problem solving. With previous findings from our individual studies suggesting intuition as pivotal in guiding students' problem-solving approaches [13, 14], we initiated this work by delving into the details of that influence. For this short paper, we have narrowed our focus to a specific aspect, posing the guiding question: *How do beyond-intro level chemistry and physics students respond to their intuitions during collaborative problem solving?*

II. METHODOLOGY

Given the novelty of our research question in these relatively unexplored contexts, we adopted a grounded approach and built upon our two previous studies by reanalyzing those datasets. In both studies, data were gathered by video-recording groups of students solving problems in a think-aloud manner, with the researcher acting as an unintrusive moderator. The students were volunteers enrolled in courses related to the respective topics at a large Swedish university. In the following, we summarize the contexts and methods of our prior studies, after which we describe the joint analysis for the purpose of this paper.

Physics context. In the context of upper-division physics, E. K. previously explored and categorized challenges faced by groups of students solving problems on the topic of statistical mechanics [13]. Data were collected from nine groups of two to three physics students, in their third- or fourth-year of undergraduate studies. Following a grounded approach, a qualitative and inductive analysis of the data allowed ten categories of challenges to emerge, three of which involved problem-solving strategies. These broad findings suggested interesting questions to explore further, such as the role of intuition in the problem-solving process.

Chemistry context. S. Y. previously investigated second-year undergraduate chemistry students working in pairs to solve a task in chemical kinetics that required them to mathematically model a chemical phenomenon [14]. Transcribed video data from seven student pairs underwent qualitative analysis, identifying the mathematical modeling processes that students engaged in, and during which of these processes that students relied on *extra-mathematical input*. Interestingly, the study showed that students relied on two distinct categories of extra-mathematical input: *chemical* and *other resources*. The latter was used to code for instances where students discussed their work in terms of how they felt, serving as a means to capture students' intuitive actions.

Joint data analysis. Guided by our shared research question, we reanalyzed data from our previous studies. We began our analysis by pinpointing instances where students either implicitly or explicitly relied on their intuitions. Implicit reliance was characterized by statements such as "I feel like..." and instances where students simply expressed a judgment without justification, while explicit reliance involved students articulating their intuitions with phrases like "my gut-feeling tells me...". During this initial phase, each researcher examined their respective dataset to ensure familiarity with the context and enable more appropriate interpretations. Following this, the authors engaged in a joint analysis. Through inductive coding, students' responses to their intuitions were categorized into two distinct groups: productive and unproductive. Continuous discussions among the authors, and other members of the research team, were held to build consensus regarding the analysis and the selection of illustrative examples. We clarify that what is considered productive in this work mainly pertains to whether the students' response to their intuitions leads to a learning opportunity, but also encompasses task success.

III. EMPIRICAL FINDINGS

By shifting our focus to how students manage their intuitions, we gained novel insights revealing that the way in which students *respond* to their intuitions significantly impacts their potential to turn those moments into learning opportunities, as well as their task success. In the subsequent sections, we present our empirical findings, providing illustrative examples of productive and unproductive responses to intuition from both a chemistry and a physics context.

A. Examples of productive responses to intuition

Physics context. In this example, Alex, Adam and Alice are discussing a task related to the distinction of microstates and macrostates, in the context of probability of finding a system in a particular configuration. In this case considering a small system with discrete energy levels and fixed total energy (see the "four atoms" problem in Ref. [13] for details). The students engage in an appropriate conceptual discussion about the problem, realizing that in equilibrium, the system is most likely to be found in the macrostate with the largest number of microstates. They proceed to solve the problem correctly. However, Adam then voices some doubt, articulating a conflict between their reasoning and his intuition.

Adam: I just have, my gut-feeling... since [laughs]...
Alex: Your physical intuition [laughs].
Adam: Yeah yeah, but shouldn't the energy be as spread out as possible? [...] When it's in equilibrium, that's like my intuitive understanding of what equilibrium means.

Here, Adam is referring to a macrostate where all the atoms of the system are in the same energy level, which is the macrostate with only one microstate but the energy is distributed equally "spread out" among the components. Adam's response is neither to trust his gut-feeling blindly nor discard it directly, rather he questions it and seeks to understand the conflict through their discussion. Alex and Alice respond by introducing a less abstract and more classical analogy, a gas in a box, to help make sense of their reasoning about the given problem. This transfer seems to be fruitful and the whole group reestablishes confidence in their answer.

Adam: Yeah yeah, I agree, I agree. I also think that that [points to their original answer] is the correct one. But my gut-feeling tells me that the energy should be spread out. Eh, but I agree with, I still agree with what we say and I wouldn't change it. [...] It's just how I, my conceptual understanding [jokingly] of thermodynamic equilibrium, which is obviously wrong [laughs].
Alex: I mean, it is probably because it's so few states, right? Like we wouldn't look at a gas with like [...] 1 mole of like, molecules, and you wouldn't expect them all to have exactly the same speed. That to me feels like, super-unintuitive as well.
Adam: Yeah yeah. And also you wouldn't look at a gas and say "that particle has all the energy" [laughs].

Overall, this response turned into a collective learning opportunity for the whole group, they even engage in discussions about why Adam might have had this intuition. This case was also productive in the sense of task success, as their response strengthened their confidence in their initial, valid solution.

Chemistry context. Students were asked to *derive the rate law of oxygen* based on information provided by a multi-step reaction. A rate law is a differential equation that describes the rate of formation of a product and should ideally not contain any terms corresponding to *intermediate concentrations*. An important feature of this task was that although the total multi-step reaction contained several molecular species serving as intermediates, only one acted as an intermediate in the formation of oxygen (see Ref. [14] for details).

In the excerpt below, Nelly and Noah are validating their rate law. They have not yet realized that only one molecular species serves as an intermediate in the oxygen formation and as a result, their current rate law is an undetermined system of equations with fewer equations than unknowns. Having spent a considerable amount of time stuck in a loop of substituting one mathematical expression for another, they begin to question their approach.

Nelly: This was a *very* complicated rate law [laughs] or are we making it too complicated? [...]
Noah: Arghhh, maybe we overcomplicated something?
Nelly: It *could* also be that we, from the beginning, chose too

many intermediates [looks at the reaction mechanism]

Noah: [...] Nah, but I think that it feels like ... reasonable that we're looking at [...] Although, actually, if we're only looking at [the formation of] oxygen, then we don't even need this intermediate [points at a compound in the reaction mechanism that is an intermediate in the total reaction but not in the oxygen formation]

Here, the students' intuitions alerted them to a potential issue, namely that their rate law was becoming increasingly complex. By acknowledging this intuition and addressing the issue—proposing that they might have made a mistake somewhere and revising their mathematical model through conceptual reasoning—they were able to complete the task successfully. In contrast to the previous example, where the students' articulated their intuitions regarding physical phenomena, Nelly and Noah's intuitions seemed more like a reflection of their intuitions regarding what to expect in the current problem-solving situation (a kind of *epistemic framing* [10]).

B. Examples of unproductive responses to intuition

Physics context. In the following excerpt, students Fran, Fiona and Filip are discussing a part of a problem involving the temperature limits of the average energy of a small three-state system (see Ref. [13] for details). Before calculating the limits, their expected intuitive answer was a maximized average energy in the high-temperature limit (which is incorrect in this case). They proceed to calculate the limit correctly, but are conflicted when it does not match their intuition.

Fiona: Yeah. But is it, is this incorrect, the "E = 0"?

Fran: Well it doesn't map with our intuitive answer.

Fiona: Yeah, but I feel like our intuition is still right.

Fiona: [A bit later] Okay, so do we say this is, our value is correct or our intuition is correct? Maybe we could look in our calculation again?

Filip: Yeah, maybe made a mistake somewhere.

In this example, the students' immediate response was to trust their intuition blindly, without justification. Similarly to other groups, they then started changing their correct calculations to match their intuitive answer (see heuristic-analytic theory of reasoning applied in a physics problem-solving context in Ref. [15]). The conflict and task remained unresolved. This episode illustrates that awareness of intuition is not always enough to respond productively, without strategies for how to deal with and scrutinize intuition.

Chemistry context. Attempting to solve the same task as Nelly and Noah, Jacob and Jonathan immediately recognize that the first step of the reaction is an equilibrium process.

Jacob: I just need to remember how we did this in the lecture [...] Ah, that's right! Because then we're gonna start using a bunch of... equilibrium constants...

This directs their focus toward deriving a rate law that includes the equilibrium constant, and at each decision-making point, Jacob and Jonathan consistently favor choices that will advance their pursuit of formulating such a rate law. While this objective was not entirely inappropriate—searching for a rate law containing the equilibrium constant can, under certain circumstances, be productive—it was not enough to solve the task at hand. Although Jacob and Jonathan did undertake efforts to validate their rate law, they never paused to critically evaluate their objective. Instead, the presence of the equilibrium constant in the final rate law reinforced their confidence in their approach (a case of confirmation bias).

Contrary to the two examples from the physics setting, where students acknowledged and explicitly articulated their intuitions, Jacob and Jonathan's reliance on intuition was more implicit. This example thus underscores not only the potential pitfalls of blindly following intuition, but also highlights the importance of helping students become aware of their intuitions.

IV. DISCUSSION

In the following, we discuss our findings, argue that *students need strategies to manage their intuitions*, and explore potential implications for teaching. We also share some preliminary reflections on the ontology and the epistemology of intuition and discuss limitations of our study.

We found that students could respond productively to their intuitions independent of whether these intuitions were appropriate or not in the considered context. Nelly's intuition of their rate law being too complex was appropriate in that situation. Although Nelly and Noah did not reflect on this intuition metacognitively, they responded to it by engaging in conceptual discussion, which ultimately led them to successfully revise their approach. By contrast, Adam expressed an inappropriate intuitive idea about a physical phenomenon related to the task. Despite this, the group responded productively by engaging in metacognitive reflection about Adam's intuition and attempting to make sense of it. This response turned the situation into a collaborative learning opportunity.

In the other two cases, both groups responded unproductively to their inappropriate intuitions. Specifically, neither of the groups scrutinized their intuitive ideas. Considering Jacob and Jonathan's apparent unawareness of their intuition, this was perhaps not that surprising. Consequently, they blindly followed it throughout their problem-solving attempt. Fran, Fiona and Filip, on the other hand, explicitly referenced their intuitions on several occasions, indicating a higher level of awareness. Still, they did not attempt to question or make sense of their intuitions. This could be due to a lack of such strategies. While this group relied heavily on their intuition without justification, leading them to modify their initially correct calculations to align with their intuitive prediction, we find it positive that they did not trust their calculations blindly.

Since our study focuses on students in more advanced level courses, it offers insights into an intermediate stage of their transition from novices to experts. Notably, we found that students at this stage possess intuitions about disciplinary content that may not necessarily stem from everyday life experiences. We further observed that students, at times, leverage such intuitions through analogies between different areas *within* the discipline. This observation supports the notion that intuition is dynamic and can evolve over time [11, 12].

Students need strategies to manage their intuitions. We assert that students can evolve and refine their intuitive understanding of disciplinary content, but also stress the importance of providing them with opportunities to develop effective strategies for *managing* their intuitions. These strategies should include techniques aimed at heightening students' awareness of their intuitions, since this is crucial for them to actively respond to, and critically reflect on, their intuitions. We therefore recommend that teachers help their students develop metacognitive skills specifically related to intuition. This aligns with ideas put forth by Kryjevskaia *et al.* [12, 15]. Metacognition as a means to mediate between analytical and intuitive reasoning has also been emphasized within CER [7, 8]. Overall, we advise teachers to create collaborative problem-solving activities where students are encouraged to articulate their conceptual reasoning, as well as their intuitive ideas and the possible origins of these ideas.

Reflections. During the course of this work, we began to contemplate the significance of understanding the various ontological and epistemological perspectives on intuition held by different actors within education. While existing literature has mainly focused on the perspectives of experts, Corsiglia *et al.* [5] underscore the importance of also exploring students' epistemological perspectives. We share the view that students' beliefs and attitudes regarding intuition likely play pivotal roles in shaping their progression toward more expert-like intuitions within a discipline. Additionally, we believe that students would benefit from a more flexible stance toward intuition—one that neither always disregards nor always trusts it, but rather seeks to understand and leverage it. To guide students in this regard, educators could, themselves, take a stance on intuition, explicitly acknowledging its existence and role in the classroom. Promoting a dynamic perspective on intuition, shifting the focus to *how students respond* to their intuitions, may also strengthen students' sense of belonging and confidence in the discipline, helping them to distance themselves from the idea that only those with "correct intuitions" belong in the discipline. A similar point about inclusion is raised in [12]. We should also pay attention to educational researchers' perspectives on intuition, as these shape the questions posed, methodologies employed, and insights derived from data. For instance, viewing intuition as exclusive to experts can lead to the assumption that student intuitions are flawed. Such a perspective may consequently perpetuate research that reinforces negatively biased conceptions about students' abilities. Conversely, viewing intuition as a universal trait expands our perspective, fosters inclusion, and grants access to pedagogically valuable questions, such as how intuition may evolve from a novice to an expert stage. In our study, embracing a dynamic perspective and moving beyond the mere categorization of students' intuitions as "appropriate" or "inappropriate" allowed us to discern nuances that might have otherwise have gone unnoticed.

Limitations. We acknowledge the influence of our theoretical perspectives (e.g., a constructivist epistemological stance) on the design and the outcomes of the study. Given the qualitative nature our work, all findings must be considered in relation to their context. At this stage, we deliberately focused our analysis on the interpretation of students' articulated reasoning and did not explore their personal perspectives on intuition. Finally, we recognize the presence of selection bias due to volunteering participants, as well as the potential influences of group interviews and our presence as moderators during the data collection in our previous studies.

V. CONCLUSIONS AND FUTURE WORK

This case study aimed to advance the research on intuition and its role in collaborative problem solving in beyond-intro level physics and chemistry. By adopting a flexible perspective on intuition, we gained valuable insights into the ways in which students approach their intuitions. Our preliminary findings demonstrate how students' responses to their intuitions could lead to either productive or unproductive outcomes regardless of the intuition's appropriateness, thus highlighting the importance of equipping students with strategies to manage their intuitions effectively. Based on these findings, we encourage teachers to cultivate a dynamic stance on intuition and create learning environments that allow for students to practice managing their intuitions through recognizing, articulating, and discussing them. On a similar note, we recommend researchers to consider the limitations associated with adopting a narrower, more static view on intuition.

This preliminary study has laid the groundwork for future directions. For example, it would be interesting to explore what processes that govern the development of students' intuitions. Various dimensions of intuition could be considered, such as intuitions *about content* and intuitions *about problem solving*. We further identified a need to expand the research on students' epistemological views on intuition. Adding to this, investigating the impact of collaborative group work on students' use of intuition could yield valuable insights. Direct explorations of pedagogical recommendations for guiding students in developing effective strategies to manage their intuitions should also be pursued.

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