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Investigating The Impact of Modelling in a CSILE on Problem-Solving Strategies and Scientific Reasoning by Students in Complex Chemical Engineering Problems

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Abstract: Pre-college and first-year undergraduate students should be able to understand and reason using complex systems in science education. However, such novice students often lack the necessary knowledge or motivation and often rely on their epistemic heuristic reasoning strategies when understanding complex systems and solving complex problems. The use of such heuristics may lead to incorrect inferences as novices lack the simulation awareness for effectively using such strategies and move towards using analytical reasoning. Such awareness cannot be taught implicitly to students unless intervened by methods that help them reflect or test their solutions. Model-Based Reasoning (MBR) activities in Computer Supported Intentional Learning Environments (CSILE) like Knowledge Forum are one such way that I hope to promote such metacognition amongst novice students and scaffold their shift towards a more analytical reasoning approach. My research aims at investigating students' use of different reasoning strategies to make sense of complex chemical systems and related concepts and the ways in which CSILE together with models and simulations can scaffold them to collaboratively refine their epistemic heuristic reasoning strategies to more analytical strategies to solve complex engineering problems effectively.

Keywords: Heuristic reasoning strategies, CSILE, Knowledge Forum, analytical reasoning, complex systems

1. Rationale

Learning chemical sciences and engineering requires the ability to make correct inferences about the relative value of diverse physical and chemical properties of multivariate complex systems. To make such judgments, learners need to identify and discriminate between variables and their relevance in understanding the complex system and solving the related complex task (Maeyer & Talanquer, 2010; Talanquer, 2013). Reasoning and working with complex systems are challenging for students as they do not understand how different variables/components work in complex systems and often memorize parts and facts related to them (Feltovich, Coulson, & Spiro, 2001). Students also often use shortcut reasoning or *heuristics* that help them understand complex systems and solve complex tasks under uncertainty or in resource-constrained situations (Talanquer, 2013). In order to build knowledge and how to go about doing that, students use certain epistemic heuristics that guide student's reasoning in their scientific practises (Krist,2019). While experts carefully select and use such heuristics effectively, novices seldom pay attention to the heuristics used and end up with an inaccurate or incomplete conceptual understanding of complex systems and suboptimal solutions to complex problems. Reasoning about complex systems analytically is essential for the foundational understanding of many disciplines (Hmelo, 2006) thus making it imperative to scaffold students' effective use of heuristics and gradually transition them towards analytical reasoning. Heuristic strategies are considered to be automatic and unconscious thereby making it essential to train students metacognitively about ways to monitor their thinking skills so as to make better judgments in appropriate contexts (Maeyer & Talanquer, 2010). Making effective intuitive reasoning and allied strategies accessible to students can foster a better understanding of the concepts (Graulich, 2010). One way to help novice learners use such

strategies would be through model-based reasoning (Won et al., 2014; Talanquer, 2013). By being able to create and manipulate the models and their variables, students can generate and refine their knowledge and understanding (Hallström & Schönborn, 2019; Magana et al., 2019). Computer Supported Intentional Learning Environments (CSILE) have been found to be useful for facilitating such creation and refinement of knowledge. However, their use for observing and refining heuristic reasoning, promoting metacognition, and gradually transitioning them towards analytical reasoning has not received much attention.

In my research, I intend to investigate the following - (a) students' use of different reasoning strategies to make sense of complex chemical systems and related concepts, (b) evolution of these strategies from heuristic to analytical when model-based and metacognitive scaffolds are provided, and (c) ways in which CSILE's knowledge building tools can be leveraged to scaffold the above two processes to enable students to collaboratively solve complex tasks effectively under uncertainty or in resource-constrained situations.

2. Literature review

Heuristic reasoning: Various studies on heuristic reasoning have identified students' reliance on the use of different types of epistemic heuristics--for example thinking across scalar levels, identifying and unpacking relevant factors, etc (Krist et al., 2019). A study showed how students themselves learned to develop a set of epistemic heuristics by engaging in scientific practises. This highlights how students understood heuristics and used them in building knowledge (Krist, 2016). Crosscutting Concepts (CCCs) as epistemic heuristics have been found to be useful while engaging in science and engineering practices like making sense of a new phenomenon. As epistemic heuristics are considered to be useful especially while making sense of a new phenomenon, CCCs can be thought to contribute to those practises by identifying productive questions and goals, supporting analogical reasoning, etc (Fick, 2019). This prior research acknowledges the use of epistemic heuristic strategies by novice students but do not focus on making these explicit and evolve into analytical reasoning strategies. Thus, while there's a need to make such heuristics visible noticeable to the students, there is a lack of research focusing on the same (Graulich,2010; Graulich,2015).

Model-based reasoning: Models are considered to be simplistic representations of the world but what aspects of the real world are considered necessary to be represented is left to the representer (Giere, 1988). Scientific modeling helps novice learners visualize and reason about their understanding of complex processes. Thus, creating and using models as explanatory and inquiry tools during the problem-solving process helps students engage in scientific inquiry and externalize heuristic and analytical reasoning used during the process (Baumfalk, 2019). While existing research highlights the usefulness of model-based reasoning for promoting scientific inquiry, very little insight exists into the use of models for helping students reflect on the epistemic criteria used by them for creating good scientific models and move towards analytical reasoning.

CSILE: Simulation-based environments allow students to interact and manipulate the scientific variables by changing input variables while they observe different graphical and visual representations of the complex scientific phenomenon (Sarabando et al., 2014). This collaborative interaction with the complex system allows students to develop higher-order thinking and research skills; crucial skills for understanding unobservable real-life phenomena (Chang et al., 2008; Koh et al., 2010). Prior research highlights how simulation-based learning might facilitate greater metacognitive self-regulation in students, helping them become aware of their choices and alternate conceptions. I plan to leverage one such environment, Knowledge Forum, to help make the students become aware of their use and appropriateness of the heuristic strategies. This is expected to allow us to make the students become aware of their use and appropriateness of the heuristic strategies in a collaborative way.

3. Research Questions

- How does a complex problem-solving task in a collaborative forum affect students' reasoning strategies in problem-solving of chemical concepts?
- How does creating models for interpretation scaffolded with metacognitive prompts and simulations for a chemical problem-solving context impact students' shift toward analytical thinking?

4. Theoretical Perspective

Our research is based on the theories of the mental model theory of logical thinking, dual process reasoning, and the theory of knowledge building. The theories of mental model theory of logical thinking believe that people can reason and reach conclusions without having complete knowledge or applying rules of logical reasoning. The learner compares the external premise with the analogous internal representation which was created as a result of basic semantic knowledge and then decided on changes (Johnson-Laird, 1989). This idea is also supported by research from Cognitive Science and Educational Psychology that talks about the dual process of reasoning (heuristic-analytical reasoning) where the heuristic step analyses for appropriate cues which are then used by the analytical process to make inferences (Evans, 1984). The knowledge-building theory is based on the principle of social constructivism and constructionism where a community of students shares a collective responsibility of working towards building their understanding of a chosen topic. Idea improvement is the basic premise of the theory and practice of KB (Scardamalia & Bereiter, 2006). Based on these three theoretical perspectives, I consider epistemic heuristics as "ideas" that get may get generated initially due to lack of complete knowledge about the complex system but get iteratively improved collaboratively over a duration of time with the help of evolving analytical reasoning.

5. Research Methodology and Study Details

The participants in my studies are pre-college and first year undergraduate students of chemical engineering. The study would be conducted in groups of 3-4 students in a collaborative set up in a CSILE, Knowledge Forum, so that the implicit reasoning strategies can be visible for interpretation in a shared environment. Models in this study are referred to the explanatory representation that is built as a result of knowledge building by students during their problem-solving process. Simulations are given to the students as part of their knowledge building process to help them in validating their sense-making process. A set of metacognitive prompts would be provided to the groups at the end of each iteration of their models. These prompts can be in the form of researcher's metacognitive questioning or check points inserted in the form of scaffolds in Knowledge Forum.

Pilot research: A pilot study was done (without a CSILE) with 7(M=6, F=1) pre-college students online during the Covid-19 pandemic. The students were asked to position themselves as heat engineers to rebuild the heat shield so that the Columbia shuttle disaster could have been avoided. The study spanned over 3 days during which they reflected on their strategies using a set of reflective prompts in a journal. This study shows a way of problematizing and refining common sense and alternate conceptions using simulations in the context of chemical education. The heuristics arising because of these alternative conceptions became more visible to the students when they started testing their proposed solutions in the heat transfer simulations on Molecular Workbench as also demonstrated in Chang et al., (2008). Additionally, the group discussion also helped them get multiple perspectives for solving the problem and refine the heuristics. Two types of students **(A):** Students who realize errors in their solutions, are aware of the heuristics used to lead to the erroneous outcome and embark upon refining their solution into an optimal solution **(B):** Students who realize errors in their solutions, are not aware of the heuristics used that lead to the erroneous outcome, and do not refine their solution were found during the study.

Future study: Findings from the pilot study provide key insights that can help the future investigation of the differences in the reasoning processes between the two types of students. The findings also inform how simulations can be used for increasing the metacognitive competence of motivated students in their use of heuristic reasoning. The future study is positioned in a CSILE to help us better understand the student reasoning processes while collaboratively solving a complex problem. . Knowledge Forum provides scaffolds in the form of prompts and a drawing environment to build new theories and engage in refinement within communities of students. Knowledge Building focuses on and encourages the notion of improvable ideas and how every idea should be critiqued and improved with better reasoning to advance the knowledge (Caswell & Bielaczyc, 2002; Scardamalia & Bereiter, 2014). The collaborative setup will enable students to engage in argumentation that would help them construct, revise and evaluate their explanatory models (Chin. C, 2010). Data collected would include models made by students, intermediate concept maps and theories in Knowledge Forum, post-activity interviews, and final solutions to the complex problems. This research aims to contribute to the existing

research on student use of reasoning strategies in model-based reasoning and problem-solving of complex systems in chemical sciences.

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