

Chemistry Simulations and Embodied Cognition: Exploring Design, Model Generation, and Collaboration

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ABSTRACT

The GEM cycle is a teaching approach with the objective of fostering understanding of unobservable phenomena in science, such as electricity, cellular respiration, or molecular structures. Simulations have enabled science students to experience and support the development of mental models. Traditionally, computer simulations have been used to support individual learning and inquiry, the cognitive advantages of paired and small group collaboration is becoming more apparent. Embodied cognition is a theoretical approach of relevance to learning contexts which defines cognition as embodied within one's interaction with their environment.

We have identified several objectives for enriched understanding in the research field of science education and student dyad collaboration. Our overall goal is to further understand how students develop conceptual understanding in the context of these interactions using a novel chemistry simulation designed by our research team. We have developed a number of research questions that study student collaboration and the possible emergence of shared understanding and mental model construction. Our preliminary research is designed to empirically evaluate our questions and facilitate the design of educational simulations for collaboration.

Author Keywords

Simulations, embodied cognition, Discourse, common ground, CSCL, mental models, conceptual change.

INTRODUCTION

Chemistry has been perceived by students to be one of the most challenging subjects to study [38] and Le Châtelier's

Principle of chemical equilibrium is considered one of the most complex concepts to understand. Le Châtelier's Principle causes difficulties in comprehension due to alternative conceptions among students [22]. It has been extensively supported that students' alternative conceptions contrast with scientifically accepted ones [23].

Alternative conceptions are created by students based on their everyday life experiences and brought with them into their learning environment [14]. These alternative conceptions by students are persistent and conventional instruction for teaching science has been characterized by some authors as largely ineffectual in fostering conceptual change [19; 42 in 39]. Conceptual change occurs when a student's alternative conceptions are modified [6; 16; 34] and can emerge through collaborative interaction which creates an environment of shared meanings and understanding [35].

The GEM Cycle

The GEM cycle is a teaching approach with the objective of fostering understanding of unobservable phenomena [10; 27]. This approach involves 1) *Generating* an initial model, 2) *Evaluating* the initial model based on new evidence and 3) *Modifying* the model if necessary [27; 28]. Empirical evidence has suggested that repetition of this process by the student results in the generation of a highly robust mental model of the concept.

SIMULATIONS IN SCIENCE EDUCATION

Simulations have afforded opportunities for science students to visualise unobservable phenomenon [40], facilitate student mental model development [17], and collaborative problem solving [36]. According to Roschelle and Teasley [36], simulations provide a mediated environment for a rich, shared understanding of science concepts through collaboration.

Within the field of computer supported collaborative learning (CSCL), the computer is being used as a medium for supporting learning through small group and dyad interaction [2]. However studying CSCL should not be limited to studying the technology but rather should include specific collaborative interactions that are supported. One

of the purposes of organising students into pairs is for the facilitation of learning and understanding through meaningful discourse and information sharing [44].

Although computer simulations have traditionally been used to support individual learning and inquiry, the cognitive advantages of paired and small group collaboration is becoming increasingly recognised [39].

SITUATED AND EMBODIED COGNITION

Recently, new paradigms of learning are emerging to inform the design of learning environments. ‘Situated’ perspectives emphasise the social, cultural and contextual factors [11; 30] of learning and place an emphasis on the embeddedness of the situation [32]. Situated cognition focuses on the importance of a meaningful context in which knowledge is acquired and promotes the importance of real-world environments for learning [4; 33; 45]. An emphasis is placed on the student being able to reflect on new situations and to recognise their personal growth through the use of cognitive tools [12; 13; 33]. These tools provide for reflection and self-regulation during problem solving [33].

Embodied cognition [1; 43] such as Varela’s enactive cognition [41] provides a distributed approach to the embodiment of the mind; it doesn’t reject the idea of artefacts and agents from the environment being represented within the head as mental models. Rather, an emphasis is placed on the mind being distributed through the brain, body, and environment, not only residing in one’s head [41]. Cognition is an embodied activity, determined by the actions of one’s body and the environmental setting where thinking occurs [7; 41]. Embodied cognition relates to learning contexts as cognition is embodied within physical activity, activity is embedded within a learning environment, and the outcome of reciprocal adaptation (e.g. student \leftrightarrow environment) is learning [45].

Although an embodied cognition perspective has framed an analysis of mathematics education [18; 32], there have been few attempts to investigate science learning from an embodied cognition approach [e.g. 37; 46] and none in chemistry. An embodied cognition approach is important for learning chemistry because like mathematics [18], chemistry uses metaphors, symbols, and imagery to represent concepts such as chemical equilibrium. The embodiment of cognition involves one’s entire body such as gesturing during problem solving [46].

Therefore, understanding how mental models are constructed through student interaction with their environment may provide clues for how knowledge is formed and alternative conceptions learnt. It is also relevant for optimizing learning with simulations because simulations aid in the learner’s mental model development [17] and provide immediate feedback through a dynamic interaction between person and environment.

SHARED SPACES FOR INTERACTION

Jeong and Chi [26] report in a study of college pairs following collaborative learning activities, that these dyads shared similar mental models suggesting that shared knowledge had been transferred during this joint activity. This provides support for the basic idea from Clark’s communication theory [8] that partners work together to develop shared understanding and establish common ground essential for communication [9].

Language embodies more than just verbal discourse [20]. It includes non-language behavioural and cognitive aspects [20; 31] which support the process of understanding communication [29]. Gee [20] refers to these components as Discourse. Non-verbal communication such as dyadic gestures (pointing) may enhance cognitive capacities [21], facilitate the development of scientific language in high school science classrooms [37], demonstrate embodied cognition [37] as a pervasive form of human communication [5; 37], and suggest cognitive development [37] even before new knowledge can be expressed through language [18].

SCIENCE CLASSROOM CASE STUDIES

Although our simulation is not yet fully functional, it is being designed to support GEM cycle conceptual learning through its components of prediction, analogy, and histogram. The prediction feature allows students to predict the outcome of a system stressor on concentrations using their current model of the situation. Functionality enables students to view prior models and evaluate present ones. The analogy feature assists learners in explaining how their initial model is representative of the larger chemical reaction. The prediction and analogy components are designed to support the generate model phase. A histogram of overall class responses to each individual’s prediction question response provides an opportunity for peer comparison and is designed for fostering self-reflection and self-monitoring of their own understanding. The histogram feature encourages learners to evaluate and modify their initial model.

Two previous case studies conducted within our Technology Enhanced Model Based Science Group (<http://m1.cust.educ.ubc.ca:8200/>) informed the design of our simulation and research questions that motivated this study. Case Study 1 was a naturalistic study that examined how a teacher helps students understand unobservable phenomena in chemistry. Observation, video and audio analysis of student and teacher classroom interaction used coding criteria designed according to the GEM cycle. Two of the model-based learning characteristics were that the teacher and students both engaged in pedagogically relevant activities of quantitative problem solving and explanations of conceptual models.

Case Study 2 was an evaluation of the Davidson simulation on Le Châtelier’s Principle of chemical equilibrium [3]. The findings revealed that when the performance of one

class of student dyads was compared with a class of individuals, the performance of the student dyads was significantly higher. This outcome, which may be the result of motivational beliefs [15] is consistent with a number of studies that postulate a relationship in student learning between communication, collaboration, and mental models [18; 36].

RESEARCH OBJECTIVES

Our overall goal is to further comprehend how students develop conceptual understanding of unobservable phenomena in the context of collaborative dyad interaction using our chemistry simulation. Our objective is to develop further understanding of how joint activities impact directly on the development of student mental models [36]. This will be accomplished through an examination of embodied activities in the context of learning chemistry with our novel simulation.

We will also examine what aspects of a technologically enhanced learning space influence social interaction and communication within student dyads. We hope to contribute to the research fields of science education and mental model construction using an integrated theoretical approach combining embodied cognition and Clark's communication theory to frame our study. We are interested in embodied aspects of human cognition and communication including the interaction between gesture, speech and cognition.

Four research questions will be addressed using dyads as our unit of analysis:

RESEARCH QUESTIONS

1. Are there differences in performance and conceptual change between student dyads using our simulation with a GEM cycle approach compared with dyads using another instructional approach to investigate Le Châtelier's Principle and chemical equilibrium?
2. In what ways does a computer simulation provide a context for scientific discourse during paired student investigation of Le Châtelier's Principle?
3. What collaborative discourse strategies (e.g. gestures) in the context of using the simulation enable students to advance their understanding?
4. Does common ground emerge through discourse (e.g. verbal conversation) and Discourse (e.g. gestures) during dyad interaction?

RESEARCH STUDY

Our investigation will involve each dyad member collaborating shoulder-to-shoulder sharing a computer simulation. The interactions will be analysed using a mixed methodology (qualitative and quantitative approaches). Pre- and post-test questionnaires will be used to assess possible changes in conceptual understanding and levels of performance. Our exploratory case study will use science students as participants and discuss whether our simulation

and integrated theoretical approach support conceptual change, scientific discourse and collaborative learning.

Empirical Experience

The primary author has empirical HCI and CSCW experience studying shared virtual environments as spaces for distributed members to collaborate. He has analysed and evaluated Shared Virtual Environments as virtual spaces for distributed participants and discussed how design features of the multi-user 3-D space encourages interaction and navigation [24]. He completed a usability evaluation of an internal virtual world to reproduce chance encounters common to the workplace by distributed work team members [25].

The study of collaborative dyads and small groups within shared spaces is a natural transition for his current Masters Thesis research. His thesis is an investigation of mental models development during dyad interactions. Specifically how conceptual change, common ground and Discourse may be influenced and emerge through collaborative problem solving using computer simulations.

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