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Developing and Evaluating an Instructional Unit on Kinetic Theory of Matter using a Complex Systems Instructional Approach

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KEY IMPLICATIONS

- An instructional approach emphasising the complexity of particulate system enhances student understanding of kinetic theory of matter (KTM) and related concepts.
- Student learning of complex phenomena can be enhanced through the use of agent-based simulation and questions-based instruction.
- Teacher collaboration is key to a successful implementation of a unit that integrates related concepts across biology, chemistry and physics.

BACKGROUND

This project aims to develop an instructional unit on KTM using complex systems instructional approach. KTM is a fundamental scientific idea which undergirds the understanding of particulate behaviours and interactions. In Singapore, KTM is introduced at upper secondary levels. Despite its importance, this key scientific idea and related concepts such as diffusion, osmosis and Brownian motion are not well-grasped by students (e.g., Ozmen, 2013). Scientists argue that these misconceptions may have arisen from students' limited understanding of complex systems (Chi, 2005).

FOCUS OF STUDY

This project aims to design a unit on KTM that acknowledges the complexity of particulate system. It begins with understanding particulate behaviours (i.e., particle moves in straight lines) before moving on to interactions (i.e., collisions). It then continues with how systemic phenomena such as random motion, diffusion, osmosis and Brownian motion emerge from the interactions. The unit uses an agent-based simulation, *NetLogo*, (Wilensky, 2003), to visualise particulate movements and questions-based instruction to construct their understanding. Three key evaluation questions are asked: (a) to what extent does the unit helps in student understanding of KTM and related concepts; (b) what are the instructional challenges teachers faced and benefits they experienced throughout the design and implementation process; and (c) to what extent do the teachers implement the instructional unit with fidelity to the complex systems instructional approach?

KEY FINDINGS

Paired-sample student t-tests were performed pre- and post-intervention. The overall results from the concept tests showed significant

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improvement in students' conceptual understanding of Particulate Movements and Interactions, Diffusion, Brownian Motion and Osmosis. For example, the mean test scores for Particulate Movements and Interactions increased from pre- (M=.64, SD=.20) to post-test (M=.80, SD=.18); Diffusion from pre- (M=.69, SD=.14) to post-test (M=.82, SD=.14); Brownian Motion from pre- (M=.21, SD=.12) to post-test (M=.67, SD=.28); and Osmosis from pre- (M=.55, SD=.19) to post-test (M=.65, SD=.18). Large effect sizes (Cohen's d=.85 - 1.68) were observed for the former three concepts, and a moderate effect size (d=.52) for Osmosis.

The teacher-collaborators also agreed in the interviews that the unit deepened students' understanding of KTM-related concepts and enhanced the learning experience. They reflected that the instructional unit was coherent and comprehensive, allowing students to construct a more canonical interpretation of the concepts. The teachers also appreciated the cross-subject collaboration. However, implementation challenges (e.g., coordinating timetables and schemes of work) remain.

SIGNIFICANCE OF FINDINGS

The findings not only suggested that the unit which emphasises complexity of the particulate system was able to deepen student understanding of KTM and related concepts, but also indicated its feasibility in real-world classrooms. The unit incorporated learning outcomes across the sciences into a coherent unit. The time needed to implement this unit was no more than the six periods typically required to teach these concepts separately. Collaborating teachers also highlighted the educational and professional benefits of this intervention.

PARTICIPANTS

Participants include seven teacher-collaborators and over 130 Secondary 3 students from two mainstream schools.

RESEARCH DESIGN

This project used a design-based research method (Anderson & Shattuck, 2012) to anchor the development of this unit. Since late 2015, the research team worked closely with teacher-collaborators from the two schools to co-design and implement the unit in 2016, and before analysing the results and refining the unit for a second implementation in 2017. Pre-/post-tests of students' conceptual understanding, lessons video-recordings and teachers' interviews formed key data sources for quantitative and qualitative analyses.

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