Drawing and Talk Reveal Dynamic Shifts in Students' Developing Knowledge of Complex Systems

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Abstract: Complex systems pose learning challenges because students must coordinate individual entities with their aggregate system properties. We sought to better understand this challenge by assessing students' drawings and speech after they learned with a computational environment (NetLogo). We assessed how students represented their knowledge of complex systems and found that students transitioned from describing key entities in speech to representing both entities and their physical properties in their drawings.

Introduction

Complex systems arise from the local actions between individual agents that produce global effects. To understand these systems, students must discern how the properties of individual agents interact to create new emergent properties (Wilensky & Resnick, 1999). Developing this understanding proves challenging because students need to recognize and reason about two aspects: (1) the interactions between individual entities that make up the system and (2) the critical properties of these entities that influence the aggregate organizational level.

Agent-based modeling environments like NetLogo have been implemented to support students in coordinating individual and aggregate level properties (Wilensky, 1999; Wilensky & Resnick, 1999). Our study aims to complement these prior approaches that relied upon talk by determining how student-generated drawings reveal students' developing knowledge of complex systems. We combine a drawing assessment approach with a think-aloud protocol that monitors what simulation features students notice during their learning experiences. This multi-modal assessment approach positioned us to understand how drawing reveals dynamic shifts in students developing knowledge. Drawing complements speech in that students' talk reveals causal interactions but their drawings reveal physical properties of systems (Ryan & Stieff, 2019; Ainsworth & Scheiter, 2021).

Our investigation focuses on a complex system at the intersection of life and physical sciences: the Resting Membrane Potential (RMP). The RMP reflects a case of dynamic equilibrium whereby two opposing processes occur at equal rates. This system challenges students to recognize how individual level properties (electrical charges) interact to produce aggregate level patterns (chemical and electrical potentials). Although the aggregate patterns prove easy to represent in drawing, students do not easily represent interactions between individual entities and their properties. Our study therefore aims to determine how drawing *and* speech illuminates shifts in students' developing knowledge. We therefore ask: how do drawing assessments augment students' speech to deliver insight into their developing knowledge of a complex system?

Methods

We recruited 50 undergraduate students (n=50) majoring in Biology and Psychology at a large Midwestern university. The research design drew inspiration from Schwartz and Martin's (2004) framework of "*preparedness for future learning (PFL)*". We randomly assigned participants to one of three instructional conditions (*PFL*). All participants were then introduced to the *same* computational experience in NetLogo (*common learning resource*).

After consent, students completed a pretest drawing. Students were then randomly assigned to one of three instructional conditions: (1) Equation Instruction approximates the instruction in physiology courses. (2) Aggregate Haptic Instruction delivered to students repeated haptic feedback with molecular magnetic models. And (3) Individual Haptic Instruction prompted students to interact with only two magnetic models by attending to the force of attraction between them.

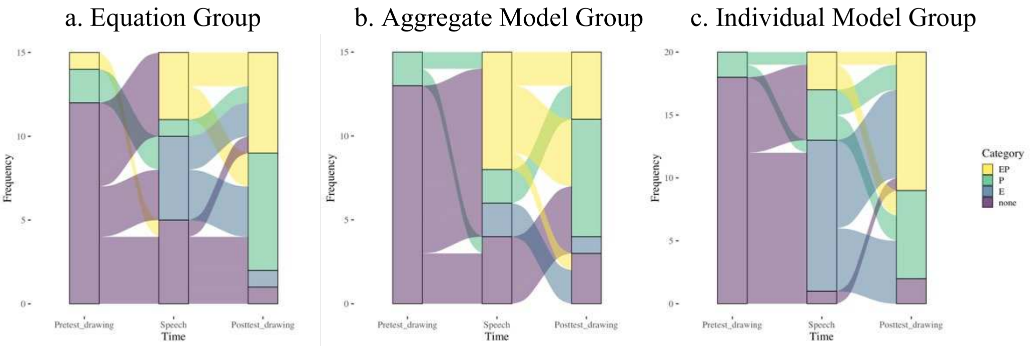
Following these instructions, all participants were guided though a think-aloud protocol with a computational environment constructed in NetLogo. Students interpreted quantitative variables, predicted, and explaining changes to the system. Last, participants completed a posttest that included the same drawing task.

Results and discussion

We analyzed students' drawings at pre- and posttest as well as their speech produced during a think-aloud with NetLogo. To assess students' understanding of complex systems, four codes emerged inductively: *Entity (E)* for the chemical identity of chloride ions, *Property (P)* for chloride ion's negative charge, *Entity and Property (EP)* for both, and *No Entity or Property (None)*. We then coded students' drawings and speech based on the presence of these four codes. Figure 1 illustrates three patterns where students shifted from representing no entity or property to representing both an entity and its property after learning with the environment.

Figure 1

The Number of Students (Y, Frequency) and Their Representation of Entity and Property (color category) across Time Points (X, assessment mode)



After conducting a constant comparative analysis of pretest drawings, speech, and posttest drawings, we observed three noteworthy patterns present across all conditions (Figure 1). First, at pre-test, most students neglected to depict negatively charged ions *(None)*, but during their computational experiences, most students began verbally noting these *Entities (E)*, their *Properties (P),* or both *(EP).* Here, the *None* frequency dropped strikingly. Second, students' attention to the *entity* chloride alone was ephemeral. Although some students noted the entity verbally during the interview protocol, few students depicted chloride alone at pre- or post-test drawing. This suggests that students were starting to identify the property of chloride's negative charge—the critical causal factor. Third, a pronounced increase in *entity (E)*, *Property (P)* and *Entity and Property (E&P)* occurred during the protocol and at post-test. This third pattern suggests that when tasked with interpreting causal interactions represented in the computational simulation or when tasked to depict these interactions in drawing, students were recognizing and representing negatively charged entities as playing a causal role.

Taken together, these patterns illustrate that regardless of students' preparedness for future learning, they transitioned from predominantly reasoning about potassium ions and their positive charges, without considering the negatively charged chloride ions, to incorporating both properties into their reasoning. This marks a critical step in their learning about the RMP because students are recognizing and representing the entity and its property needed to explain the emergent phenomenon (i.e., the electrical potential) in the complex system.

Our multi-modal assessment delivered the critical insight that students' speech alone can obfuscate their developing knowledge of a complex system. This pattern is most salient in the individual model group (Figure 1c). Although many students noted only the entity (chloride) in speech, none of these students represented the entity without its physical property (negative charge) when they drew at post-test. The other groups displayed a similar pattern. This demonstrates the value that student-generated drawing holds for assessing students' developing knowledge of complex systems. We echo Ryan and Stieff (2019) by underscoring that students likely do not make deliberate choices when describing or representing their knowledge. For this reason, we argue that multi-modal assessments allow students to "draw" upon their developing multi-modal knowledge.

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