Diagnosis of Misconceptions With Coherent Underlying Structure in Learning Diffusion

Man Su, Arizona State University, mansu@asu.edu
J.Yohan Cho, Arizona State University, jycho2@asu.edu
Brandon Vanbibber, University High School, brandon.vanbibber@tuhsd.org
Jesse Ha, Arizona State University, jessha@asu.edu
Michelene Chi, Arizona State University, michelene.chi@asu.edu

Abstract: This classroom study, involving 149 high school students, investigates structure, coherence and frequencies of misconceptions students have while learning diffusion via a simulation. The results show that misconceptions are not random ideas, but rather have underlying structures and can be systematically characterized by the PAI*R*-*C* framework, which aims to help students understand the nature of emergent processes embedded in their school curricula. The article concludes with a discussion of implications to foster deeper understanding of misconceptions from a systematic, structured perspective.

Introduction

Distinct causal structures and mechanisms underlie emergent and sequential processes, causing misconceptions to consistently appear when students interpret emergent processes from a sequential mindset in science classrooms (Chi, 2013). When learning the concept of diffusion of ink in water, which is an emergent process, it is common for students to explain the visible flow pattern of the ink molecules "The ink molecules want to go in that direction because it's less dense over there.". In addressing these robust misconceptions, a significant strand of work has focused on conceiving misconceptions from a fragmented perspective (diSessa, Gillespie, & Esterly, 2004; Leonard, Kalinowski, & Andrews, 2014), that concepts are built by experiences activating different knowledge pieces, or phenomenological primitives (diSessa, 1993). Nevertheless, the awareness of underlying coherence shown in misconceptions across science processes prompted an alternative interpretation which conceives misconceptions as having systematic underlying structure (Chi, 2005; Chi et al., 2012), with a set of contrasting feature characteristics for the two kinds of processes. Table 1 below shows the features and characteristics of two dimensions of the PAI*R*-*C* framework, the ***Relations*** among the interactions, and the ***Causal*** relations between the agents and the pattern (Chi, submitted).

Table 1: The PAI*R*-*C* Framework: Features with Contrasting Characteristics for Two Kinds of Processes

	Definitions	**Sequential Processes**	**Emergent Processes**
R	**Relations** among the interactions (Comparing agents' interactions)	*Distinct Set* *Restricted Other* *Serial ordering* *Dependent*	*Same set* *(Unrestricted) Random Other* *Simultaneous* *Independent*
C	Agent-pattern causal relation: Characteristics and implications	*Centralized or individualistic Control* - *Special status* - *Global goal: intentional*	*Decentralized or distributed Control* - *Equivalent status* - *Local goal: unintentional*
	Agent-pattern mapping relation: Manifestations	*Align: Corresponding* - *Same direction*	Not align: *Disjoint* - *Not same direction*
	Agent-pattern causal mechanism (How the perceptual pattern is produced)	*Cumulative summing:* *Summing between time*	*Collective summing:* *Summing within time*

The PAI*R*-*C* conceptual framework defines processes by its **P**attern (overall changes by a process that are often visible and meaningful), the **A**gents (elements that participate in the process which produces the pattern), the **I**nteractions of the agents (how the agents of the process interact), the **R**elations among the interactions, as well as the agent-pattern **C**ausal Relations, that make up processes. According to the framework, the example mentioned above of robust misconceptions about diffusion can be characterized by the implication of the feature *Centralized or Individualistic control* and the implication of the ink molecules having *Intentional Global goal* which is attributing an Emergent process with a Sequential process feature characteristic and implication.

We attempted to teach science concepts from the PAI*R*-*C* perspective. Our instruction included dynamic simulations that show the macro-level pattern emerging from the collective net effect of the micro-level interactions between agents (Chi et al., 2012).

This study examines students' misconceptions about diffusion through a simulation activity. Specifically, the purpose of this study is to validate the PAI*R*-*C* framework in a science classroom by aligning students' misconceptions with PAI*R*-*C* features. Our research question is 1) Based on the PAI*R*-*C* framework, what features of the PAI*R*-*C* framework do the misconceptions represent?

Method

Participants and research design

This study was conducted in a high school in southwestern United States. Participants (N = 149) were assigned to one of two conditions using stratified random sampling method. Students in the experimental condition (n = 95) were given two lessons: 1) an overarching PAI*R*-*C* Process Module containing information about the concept of emergent causality by comparing and contrasting everyday "emergent" and "sequential" processes; 2) a PAI*R*-*C* Passive Transport (simple and facilitated diffusion) Lecture with a Simulation activity and PAI*R*-*C* practices. Students in the control condition (n = 54) were given two lectures as well: 1) a Nature of Science Module, a traditional module introducing the philosophy and methods of scientific exploration; 2) a "Business as Usual (BAU)" Passive Transport Lecture with the same Simulation activity but BAU practices aligned with a traditional biology curriculum. The same pretest and posttest on diffusion were administered between the two groups before and after the second lesson. Both groups also devoted equal amounts of time learning diffusion.

Procedure and data analyses

To examine students' misconceptions about diffusion, we coded student responses to prompt questions within in the simulation activity. We used a three-step process to code and analyze students' prompt responses. First, we compared the prompt questions provided for the two groups during the simulation activity. We have identified 10 invariant set of prompt questions out of 15 questions for the control group and 18 questions for the experimental. Second, we carefully selected two pairs of identical prompts, which asked generative questions that required students to infer and explain their observations. Third, two lab researchers previously trained in the PAI*R*-*C* framework screened students' prompt responses to the selected prompt questions in order to check the correctness and categorize the misconceptions from the PAI*R*-*C* perspective for incorrect responses. Inter-rater reliability was checked, and any disagreements were resolved by consulting a biology teacher who was affiliated with the lab and also instructed the two groups.

Simulation and simulation prompts

For both groups, students were provided with an identical simulation that showed the agent and pattern levels for Diffusion (from Pearson) and were given prompts composed of self-explanatory questions. The simulation consisted of two types of molecules, which moved around and collided with one another, illustrating how diffusion works (Figure 1). We have completed coding of two selected prompt questions. For the first prompt, the molecules do not cross the membrane, but for the second prompt, students selected a simulation feature that allowed blue molecules to cross the membrane but not orange molecules. Data was collected from 37 students in the control group and 69 students in the experimental group. The first prompt was: 1) Is diffusion still occurring? How do you know? This prompt has generative questions because a correct response would imply one understands that molecules are still moving randomly and colliding with other molecules. The second prompt was: 2) Which molecules are diffusing across the membrane? Why do these molecules move in this pattern? This question, on the other hand, is quite difficult for students to answer correctly because it requires a deeper understanding of the agent-pattern inter-level causal relationships. Students who have better understanding would interpret that the blue and orange molecules are bumping into each other without following a set pattern.

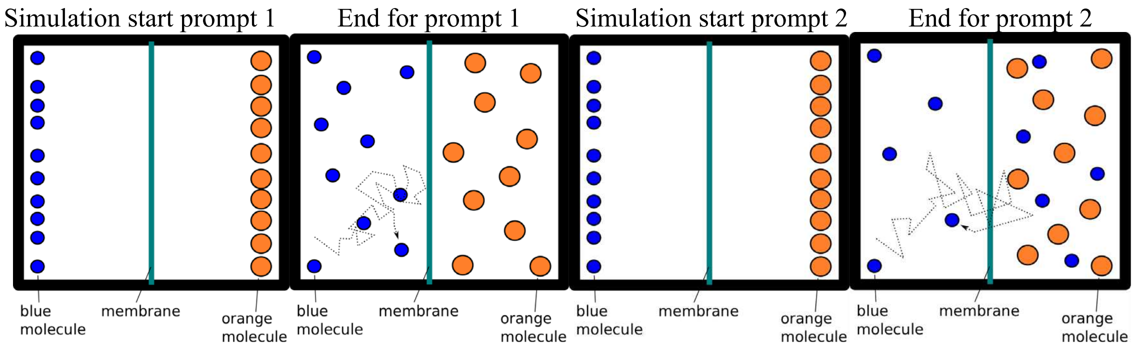

Figure 1. Schematic Drawings of the Diffusion Simulation for Prompt 1 & Prompt 2.

Findings and discussion

Since misconceptions were prevalent in both groups, we reported the proportion of misconceptions among all incorrect responses: the categories and frequencies of overall students' misconceptions reflected in their responses to the two simulation prompts. Based on the coding result of 106 valid responses, 74% of responses were incorrect for prompt 1, while 84% of them were incorrect for prompt 2. We counted misconceptions from these incorrect responses.

As shown in Figure 2, responses displaying misconceptions made up 38% of the total incorrect responses for prompt 1 and 44% for prompt 2. The more intricate prompt appears to produce a proportionally higher number of misconceptions. These students did not transfer the knowledge learnt from the overarching framework to address the prompt questions, especially for the second prompt which asked a question requiring understanding of agent-pattern causal relation.

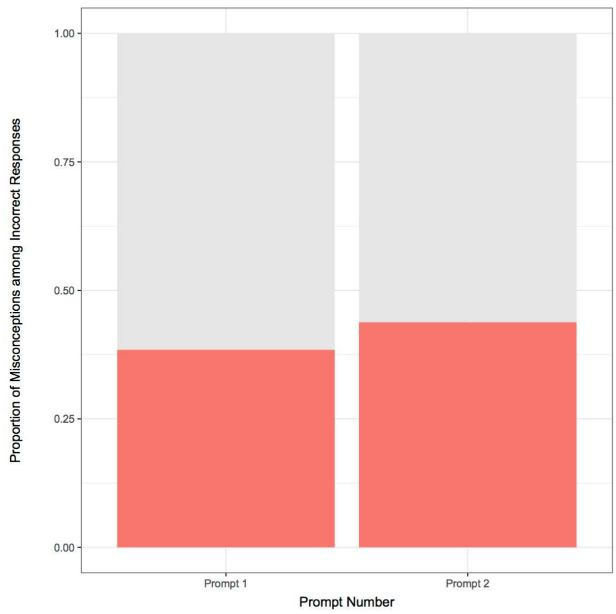

Figure 2. Proportion of misconceptions among incorrect responses, across prompts.

There were three main categories that the 69 misconceptions identified from incorrect responses across the two prompts (see Table 2) fell into. They were *Align: Corresponding (same direction), Centralized or Individualistic control, and Restricted other*. In reference to the PAI*R-C* framework (Table 1), two common sub-categories of misconceptions were diagnosed for *Centralized or Individualistic Control, i.e. special status; global goal: intentional.* In terms of frequency, prompt 1 revealed more misconceptions in the category of *align: same direction* and *restricted other*, whereas prompt 2 revealed more misconceptions in *special status* and *intentionality.* Among all misconceptions, the highest frequency of misconceptions appeared in the *global goal: intentional* category (n = 27). Because one student's response demonstrated two categories of misconceptions in the coding process, we decided to present the frequency of misconceptions instead of the number of student responses showing misconceptions.

Table 2: Categories and Frequencies of Students' Misconceptions Revealed in the Diffusion Simulation

	Align: Corresponding (same direction)	Centralized or Individualistic control		Restricted other	**Total frequency of misconceptions across categories**
		(special status)	(global goal: intentional)		
Frequency of misconceptions for prompt 1	11	5	7	7	30
Frequency of misconceptions for prompt 2	5	14	20	0	39
Total frequency of misconceptions across prompts	16	19	27	7	69

Some typical misconceived responses were: "because the molecules are not moving from high to low concentration." (*align - same direction* for prompt 1); "because only the blue molecules can pass over the membrane." (*control* - *special status* for prompt 2); "They are the only ones that can cross the membrane. They still want to reach equilibrium, so they continue diffusing." (*control - global goal: intentional* for prompt 1); "diffusion is not occurring because the molecules are at equilibrium." (*restricted other* for prompt 1).

Conclusion

This study investigated whether the PAI*R-C* framework, if taught to students, will help them understand the nature of emergent processes which is part of their school curricula. Accordingly, an overarching framework about everyday processes (both Sequential and Emergent) was created and taught to students, prior to teaching them about the concept of diffusion. The hypothesis of the entire project was that providing an overarching framework—in contrast to other frameworks often presented to students such as The Nature of Science—might help students understand concepts of diffusion better than if they were only given The Nature of Science prior to instruction more specific on the concept of diffusion. In our efforts to measure students' understanding of diffusion during a simulation activity, we noticed that they continued to have persistent misconceptions, and that these misconceptions can be coded systematically to align with the features of the PAI*R-C* framework. The result indicates that students' misconceptions reflect a coherent underlying structure, contradicting the assumption that misconceptions are a result of added experiential pieces of knowledge.

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