Changing Explanations about Sand Dune Movement

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Abstract: Knowing that students tend to have difficulties understanding complex systems, this study investigates one case of an adult student’s reasoning about how sand dunes move in the desert. The movement of sand dunes is a phenomenon that exhibits characteristics associated with complex systems. During the course of the interview, the student generates a set of consecutive explanations and over time her explanations shift from being gradually less prototypically centralized to more decentralized. Using the Knowledge-in-Pieces epistemological framework, I document a series of knowledge configurations that are used within her explanations that together support this change. These results have implications for future work focusing on identifying factors that support similar kinds of changing explanations.

Introduction

Students’ tend to have difficulties when learning about complex systems (Chi, 2005; Jacobson, 2001; Resnick, 1996; Resnick & Wilensky, 1998). Complex systems are composed of individual elements, each of which has a particular pattern of behavior that results in a macro-level behavior that is different from the micro-level behaviors. As a simple example, consider a “wave” traveling around an arena, each individual follows a simple micro-level rule in which they raise their hands immediately after the person next to them raises their hands. This rule contributes to a macro-level pattern in which the entire “wave” travels around the arena. Some other examples of complex systems include the formation of traffic jams, the movement of flocks of birds, and the symmetrical patterns in snowflakes. Across students’ difficulties when learning about these systems is a common theme of applying centralized or direct causality in situations where decentralized or emergent causality is more appropriate. For example, when learning about diffusion, Chi (2005) finds that students’ misconceptions about emergence are due to a misinterpretation of these processes as a kind of direct process.

An example of this difficulty comes from Resnick (1996) who focuses on the so-called “centralized mindset,” which is a way of thinking, or attitude, in which centralized causality is presumed to account for the system’s behavior even in cases where decentralized causality is appropriate. In the context of building computational models of various complex systems, including traffic jams and the formation of termite mounds, Resnick (1996) documents both the pervasiveness of the centralized mindset and ways that students can begin moving towards decentralized causality. This difficulty can be illustrated through the case of the wave; one could use centralized causality by assuming that there is an announcer telling each person when to raise his or her hands or by assuming the existence of a norm in which one seating section of the arena begins the wave every time the favorite team scores. Oppositely one could employ decentralized causality by assuming that the wave has a distributed cause in which each person individually decides when to raise his or her hands.

Knowing that students have these difficulties, there is a focus on instructional approaches to support students towards thinking about complex systems using decentralized causality instead of centralized causality. Sengupta and Wilensky (2009) implement a computational modeling curriculum about electricity, and they hypothesize that it supports students by bootstrapping their existing intuitive knowledge. Similarly trying to support students thinking about emergence, Levy and Wilensky (2008) discuss the utility of a strategy in which an intermediate level is used to scaffold students’ understanding towards decentralized causality. Using this strategy students’ reason about a pack of deer or clique of students as examples of small groups within larger populations.

I build off this prior work, in that I also investigate ways to make progress towards reasoning about complex systems using decentralized causality. However, I investigate a slightly different issue. As mentioned above, prior work generally focuses on whether students can make progress understanding complex systems, what strategies are effective, and how might computational modeling curriculums be effective. Comparably I focus on how progress occurs moment-by-moment in terms of changing knowledge. Penner (2000) also looks at changing explanations, although he focuses on content and not on forms of knowledge or knowledge evolution.

This paper falls within a growing body of work in the learning sciences that focuses on the process of learning in terms of developing theories of knowledge and of knowledge evolution using fine-grained moment-by-moment analyses (e.g. Schoenfeld, Smith & Arcavi, 1993; Sherin, 2001). While I build off this prior work using a similar methodological approach and emphasizing changing knowledge, this study focuses on a new domain, complex systems, and focuses on pools of knowledge that are activated for systematic use in a context.
Theoretical Background: Process Analysis of Local Changes
This paper uses the epistemological framework of Knowledge-in-Pieces (diSessa, 1993) to capture the process of local changes across a student’s explanations in terms of knowledge. By local change I refer to small changes that occur in a moment-to-moment time scale during a 13-minute discussion. I focus on explanations that address how and why the phenomena occur and on the knowledge activated within the explanations. Specifically, I focus on the pool of knowledge that has been activated for systematic use in a context. I refer to the pool of knowledge as local knowledge configurations, as they depend on and are activated within a context. Knowledge configuration is not a highly technical term, they are not homogenous, and some bear close relationships to existing constructs. Knowledge configurations may be locally coherent (Hammer, et. al. 2005) as they are dynamic, emerge from a pool of knowledge, and hold together for a short time period. Some knowledge configurations bear a resemblance to Dynamic Mental Constructs (Sherin Krakowski & Lee, 2012) as they are dynamic mental states that can shift during an interview and that depend on many factors including interview questions. However, some knowledge configurations are more like resources that influence explanations rather than explanations themselves. A goal in this analysis is to address cases of knowledge facilitating change within and across explanations.

While I focus on the process of local changes during short time periods in terms of the knowledge within a student’s explanations, there is another perspective that focuses on the general causal patterns within students reasoning. For example, Perkins and Grotzer (2005) present a taxonomy of increasingly complex causal models. Andersson (1986) identifies a common causal core to explanations across different scientific topics. Overall these perspectives focus on general causal patterns within explanations. Comparably, my analysis focuses on how complex arrangements of knowledge support shifts within causal explanations.

The goal of this paper is to describe the changing explanations in terms of the knowledge configurations about a particular phenomenon that exhibits a behavior associated with complex systems—the movement and formation of sand dunes. I highlight the interactions of knowledge configurations that support a shift from gradually less prototypically centralized towards decentralized. This paper resides within complex systems, a field which generally does not investigate the process of changing explanations in terms of knowledge, and within an area that often focuses on sequential patterns of causal reasoning rather than a complex arrangement of knowledge.

How do sand dunes move in the desert?
This study focuses on students’ reasoning about the movement of sand dunes in the desert, an understudied, but useful, example of a complex system because of students relevant intuitions and experiences. There is little discussion about this particular problem, but I hypothesize that it is accessible for the purposes of investigating learning about complex systems. Students have a great deal of underlying intuitive knowledge about the wind and sand from everyday activities such as playing in sand boxes or gardening. Additionally, since students likely have not thought extensively about sand dunes prior to the interview, we can see them activating intuitive knowledge while reasoning about new phenomena.

From the scientific perspective there are several different ways to view the movement of sand dunes. Fundamentally, the movement of sand dunes is a complex process, because the movement of the entire dune (collection of many particles) is determined by the movement of individual particles which act as independent agents with no external cause orchestrating their movement. From the geological perspective, one main mechanism for how wind moves sand is known as saltation. Saltation is the process by which the wind moves sand particles through successive small jumps. When a particle lands it may be ejected or it may collide with another particle resulting in that new particle being ejected. Using Newtonian mechanics each jump can be modeled as a projectile. This process is thought to account for the majority of sand moving up the less steep side of the dune and being deposited on the steeper side. Hence dunes often, but not always, move leeward, in the direction of the wind (Pye & Tsaro, 2009). However, there are many types of sand dunes with different shapes and different behaviors. From the perspective of complex systems, the movement of sand dunes occurs through the local interactions of individual sand particles. Each particle has a particular behavior, for example it can join a dune, leave a dune, or not move. The macro-level behavior of the entire dune, moving, staying still, or staying in the same location but changing size, is due to the collective behavior of all individual sand particles.

Using the centralized/decentralized distinction, we can hypothesize how students might explain the movement of sand dunes. If students apply centralized causality when explaining the movement of sand dunes, they might focus on the wind controlling the movement of sand particles such that a gust of wind blows all the sand particles simultaneously thus moving the sand dune at once. While this idealized explanation might sound implausible, a version that I have seen in other interviews is that there must be a boulder in the desert, acting as a seed or leader, such that sand hits the boulder and a dune forms at that location. In contrast, one could use
decentralized causality by assuming that wind moves each sand particle a distinct and random distance independent from surrounding sand particles. In this more normative model, the desert is composed of many sand dunes and innumerable sand particles, all acting independently. In this model, it becomes irrelevant whether a new dune is composed of the same sand as in the old dune, since all dunes are indistinguishable from one another.

**Methods**

The data in this paper comes from a short excerpt within a longer open-ended interview with Laurel, an adult student who articulately reasons about the movement of sand dunes. This interview comes from a corpus of open-ended clinical interview data in which 8th–12th graders, undergraduates, masters, and Ph.D. students explain how sand dunes move. This study uses open-ended individual clinical interviews in the style described in diSessa (2007) to focus on moment-to-moment changes, allowing the author who serves as the interviewer, to probe the student’s knowledge. In the Laurel interview the sand dune discussion began 38 minutes into an hour-long interview and lasts for 13-minutes. The rest of the interview, before and after the sand dune discussion, is spent discussing unrelated physics topics that do not involve sand dunes or emergence. At the beginning of the sand dune excerpt I propose an initial situation of one sand dune moving in the desert. Additional probing questions focus on clarifying her understanding of the underlying mechanisms (e.g. “You mentioned at one point that it would, like, the sand, would stick to it. How would that work?”). Laurel is a masters-credential student in mathematics education. She has an undergraduate degree in mathematics and has taken introductory physics. She does not have any formal training in geology, sand dunes, or complex systems; therefore, this is a case of an adult reasoning about something that is new to her. I chose the case of Laurel because she is very articulate and clear in her explanations. We can see local changes in her thinking over the short time period. Data consists of the student drawings and video records of the interviews, which I then used to create transcripts.

My analytical goal is to capture and describe the ways that her explanations change with an emphasis on knowledge. Through an iterative coding process, it became apparent that certain explanations and knowledge elements are central to her reasoning shifts. This general method falls within a family of related theoretical and methodological approaches which focus on describing the nature and development of knowledge systems known as Knowledge Analysis (Sherin, 2001).

There are some interesting methodological differences between the current study and much of the prior work focusing on students’ thinking about complex systems using decentralized causality. The current literature (e.g. Sengupta & Wilensky, 2009) tends to use computational modeling environments and a pre-/post-test approach, sometimes with interviews, to understand general trends in students’ learning. Comparably, the current study only uses interviewing techniques in which students engage in a thought experiment after being presented with a hypothetical situation, sand dunes moving in the desert. Although students have the option of drawing, there are no computational or physical manipulatables.

**Analysis: Description of the Knowledge Configurations that Facilitated Change**

In this analysis, I describe a series of knowledge configurations that are used within her shifting explanations. At the beginning of the discussion, she generates a series of explanations that are based on knowledge about the implausibility of direct causality. As the discussion progresses, her explanations shift as she generates and subsequently rejects explanations based on sand moving in sequential layers. Another shift in her explanations occurs when she generates explanations based on the sand stickiness mechanism for how sand joins and leaves dunes. Simultaneously during these shifts she also occasionally focuses on the origin of dunes, asking herself questions about how dunes begin forming and what resides in a particular location after a dune moves. This list of knowledge configurations that are aligned with shifts in her explanations is not exhaustive, other factors include interviewer questions and her shifts in her interest or focus of attention, but this list is meant to illustrate some central knowledge configurations. Her final explanations account for a configuration of knowledge that I refer to as changing composition, in which the size of the dune may be stagnant while sand particles are constantly joining and leaving at equal rates. By the end of the discussion, she relinquishes explanations that are prototypically centralized and generates the changing composition explanation, which is more decentralized.

**Implausibility of Direct Causality**

One key way in which Laurel's explanations change is by her recognition and subsequent rejection of the plausibility of direct causality. Throughout the interview, Laurel several times rejects explanations that incorporate knowledge that is based on direct causality. At first Laurel rejects an explanation based on a single dune shifting positions in its entirety: “I don’t think the wind would blow the whole sand dune all at once.” A second time this occurs is when
she rejects the idea that all the sand particles that comprise the old dune will be moved to the new dune: “I don’t know how they [sand particles] would all end up in the same place…I don't know why they [sand particles] would all concentrate in a form, a big pile.” A third time this occurs is in the context of discussing the dune shifting locations in sequential layers. Laurel rejects this sequential layers explanation because it relies on the wind being consistent which conflicts with her prior experiences of wind being variable.

“This top layer of sand would kind of get blown first…outside of the sand dune [hand motion] would kind of get blown over here and then it would kind of end up somewhere and then now that layer gone so then if the wind kept blowing, then it would kind of blow, whatever, this, some of the outside again….it’s not like the wind is constant, it's always blowing in exactly this direction at exactly the same, exactly the same strength. Because if it were that would make sense right.”

The theme in all these examples is that she is considering the plausibility of direct causality and then rejecting the implications of this approach based on some underlying knowledge about the motion of the wind and sand.

Rejecting the plausibility of direct causality contributes to her changing explanations, because it opens doors for considering other options. For example, rejecting the idea that all the sand particles that comprise the old dune will be contained within the new dune opens the door for her to consider the role of other sand in the desert, that might join or leave a dune coming from or returning to the surrounding desert, which is associated with decentralized causality. A similar example occurs when rejecting explanations based on the dunes moving in sequential layers. She has an expectation that for this process to hold, there needs to be a consistent wind. However, her prior knowledge suggests that the wind is not consistent, thus, allowing her to reject the sequential layers explanation and opening the door to consider a variable wind.

**Sequential Movement**

A key point during the interview, when her explanations shift is when she generates and subsequently rejects explanations based on sand moving in sequential layers. She generates two versions of this explanation, in one case the layers of sand move sequentially with the outermost layer moving first, followed by the next layer until the entire dune moves. In the other version of this explanation, individual grains of sand move sequentially. She mentions an imaginary situation in which a bird drops grains of sand sequentially on the same location until a dune forms: “If a bird comes and takes one grain of sand and then dumps it, cause if that happened, then obviously, if you keep dumping them on top of each other it would be like, when you dump whole bunch of sand and it makes like a cone shape.” For both versions of this explanation, she rejects it because the wind does not work this linearly, she expects there to be a more variable wind.

These explanations are an important intermediate step because they direct her to focus on the microscopic level of individual sand grains, and because they highlight the variableness of the wind. As mentioned in the prior section, recognizing the implausibility of direct causality, in this sequential movement, is important because it opens the door for her to consider more variable wind. Also, this explanation is important, as it connects the micro-level movements of individual grains of sand with the macro-level dune changing size. Connecting levels is an important part of decentralized explanations (Sengupta & Wilesnky, 2009).

**Sand Stickiness**

One factor that influences Laurel’s shifting explanations is a focus on how sand joins and leaves the dunes, based on a mechanism I refer to as sand stickiness. Sand stickiness is that idea that sand particles suspended in the wind join the dune because they stick to the dune resulting in it getting bigger and sand particles leave a dune because they are no longer stuck resulting in the dune getting smaller. Laurel incorporates this mechanism for how dunes change size in several her explanations. For example, when explaining how dunes get smaller Laurel says:

“I guess, since the sand is like kind of loose [gesture implies outwards], its not like it's glued together or compacted or something [holds hands together to imply compact]. Then when the wind comes, the sand will freely, the outside layer of sand will start, can just fly other places [gesture implies away] and then maybe that keeps happening as the wind keeps coming then next, other layers of sand keep disappearing or not disappearing but like, being taken off of that and then it's like dissipated around [gesture implies inwards and outwards].”

This is one of several explanations Laurel generates based on this mechanism, which is important, because, similar to the sequential movement explanation, it connects the micro and macro levels.
Origin of Dunes
Throughout the discussion, she occasionally focuses on the origin of dunes asking herself questions about how a sand dune began forming and what is left over after a sand dune moves. The first time she mentions the issue of dune origins is in the context of what happens after a dune moves. Laurel asks herself, “originally where there was a sand dune, would it be flat or something? Or? Just shorter?” At the end of the interview, the possibility of the location of the original sand dune not being flat becomes relevant. Instead of focusing on what is left over after a dune moves, Laurel considers an alternative, but related question, of why a dune doesn’t disappear and how it gets bigger after having gotten smaller. “But it wouldn't get flat probably, there would still be a little cone there and then maybe that would start collecting more [gestures implies collecting] and growing [gestures implies growing] and then the wind could take it away get smaller [gestures implies getting smaller].” Laurel rejects the idea of a dune disappearing into the flat desert and focuses on dunes getting bigger and smaller cyclically as sand joins and leaves.

The question of the origin of dunes is associated with a shift from explanations that are gradually less prototypically centralized to decentralized. Laurel’s initial approach to this question focuses on the desert being flat after a dune moves, which is aligned with centralized causality while at the end of the interview, she rejects the flat desert idea and mentions a small cone of sand left over which then allows the dune to begin increasing in size.

Discussion and Conclusion
In the analysis, I describe some candidate knowledge configurations that facilitate change in Laurel’s explanations from being gradually less prototypically centralized to more decentralized. For example, in this data, recognition of the implausibility of direct causality and focus on the origin of dunes is important to her changing explanations. The ways in which Laurel’s explanations change may have implications for future work focusing on identifying factors that support students’ reasoning about complex systems.

References

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