

Generating Explanations for an Emergent Process: The Movement of Sand Dunes

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Abstract. The movement of sand dunes in the desert is an emergent process; the overall movement of a dune is influenced both by the random interactions among individual sand particles and by the process of wind adding and subtracting sand. People often misconstrued emergent processes as deterministic processes containing central causality. I present a case study of how one person, an adult, who was not an expert in physics, articulated and refined her explanation of the movement of sand dunes. She began with centralized causality but ended with an explanation containing the cogent emergent ideas. This case study is noteworthy in exemplifying the dynamic process of generating an explanation. The interviewee went through four different explanations at three different levels (macro, micro and mid-level) and concluded with an explanation that simultaneously addressed the movement of sand dunes at all three levels.

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INTRODUCTION

How do lay people see, understand, and explain physical phenomena that rely on complex causality? As part of a larger investigation into novices' and experts' conceptual understanding and scientific explanations, I present a case in which an adult, who was not an expert in physics, constructed a genuinely emergent scientific explanation for the underlying machinery of an emergent process. Over the course of the interview she constructed four explanations, of which the final one was the cogent emergent explanation.

Emergent processes are a type of complex process in which the random or probabilistic behavior at one level (e.g. the microscopic level) gives rise to different behavior at another level (e.g. the macroscopic level). In many emergent systems the properties of the system emerge as a result of the underlying interactions among the components within the system [1]. People often misconstrued emergent processes as deterministic processes containing central causality [1,2] and people also have trouble understanding randomness and probabilistic processes because randomness can give rise to non-random phenomena [3]. Examples of emergent processes include the formation of traffic jams [4,2], the formation of a talus slope [4], and student's role-playing of physical particles [3].

The movement of sand dunes across a desert, how they increase and decrease in size, is an example of an emergent process. Specifically, in this case both the random interactions between the individual particles of

sand and the wind, influences the overall movement of dunes or the change in sizes of dunes. In this case there are three relevant processes: 1) the rate at which the wind deposits sand particles on a given dune 2); the rate at which sand particles are picked up by the wind from a dune; and 3) the rate at which sand particles cascade downwards due to gravity. By paying attention to how these rates combine, one can unpack how dunes grow larger or smaller. One can then implicitly deduce how a dune might gradually move across the desert by imaging these rates being unevenly distributed on different sides of a dune.

The case study I present is noteworthy for how quickly the dynamical process of refining an explanation unfolded over a short period of time. During the interview, four different explanations were discussed, accessing a variety of resources [5]. One main difference among these explanations is the level (macro, micro, and mid-level) at which the phenomena was discussed, some explanations were only at the sand particle level while others were at the entire dune level. However, the final emergent explanation simultaneously addressed the phenomena at all three levels. The shifts between these different explanations was rather dramatic, some explanations were explicitly rejected due to recognized flaw based on the resources the interviewee was able to access at that given point in time.

METHODS

The analysis described in this paper come from a series of clinical interviews in which people were

asked to generate explanations for a variety of phenomena in physics. In this paper I focus on one sub-set of one interview: the dynamics of sand dunes.

In this paper I focus on an interview with an adult, Laurel (a pseudonym), who was a graduate student in a master credential teacher program and had a background in mathematics. Her science background consisted of standard high school science (chemistry, earth science and biology) and one semester of a college physics class that was intended for non-physical science majors. She volunteered for the study through a general recruitment email that had been sent out to graduate students at a large research university. This paper focuses on Laurel because she was rather successful in generating the cogent emergent explanation and she was particularly articulate and clear in her explanations. Interviews with other participants contained some attributes similar to Laurel's, but her case is unique in regards to how many different explanations were used. Additionally, in situations where basic causality is well-understood her case can assist in understanding how non-experts can and do generate more sophisticated explanations than is expected.

The clinical interviews were conducted in the style outlined in diSessa [6]. The interviewer went into the interview with several pre-determined questions. For example, most participants were asked not only how dunes move, but also how a single dune might get bigger or smaller. During the interview, the interviewer generally followed the interviewee wherever they chose to go and asked follow-up and clarifying questions that focused on the how and why dunes move and change size. For example, Laurel once mentioned that the wind "...makes them somehow reformulate that sand into, like, a new sand dune." The interviewer followed up this statement by asking "How would the wind reformulate the sand?" Additionally, the interview never introduced a new level into the discussion. The intent was to make the interview an extension of a natural conversation. The interview was video-taped, transcribed, and analyzed using methods discussed in [7].

THE CONSTRUCTION OF THE EMERGENT EXPLANATION

The Deterministic Explanation

During the interview Laurel considered and then rejected the deterministic explanation three times; due to space limits in this paper I present two out of the three examples. In these explanations Laurel is not explicitly rejecting the exact same thing, instead these

explanations highlight different aspects of the deterministic idea and the flaws Laurel recognized. Simultaneously, while seeing flaws in these explanations Laurel highlights different resources that are productive later on.

Laurel firsts rejects this explanation at the beginning of the sand dune discussion, by saying, "cause I don't think the wind would blow the whole sand dune all at once. But it could blow all the little, [pause] all the little, all the, the little sand molecules, like whatever // umm // like little by little." She has rejected the idea of the wind blowing the entire sand dune at once, in other words, she has rejected centralized causality in which a sand dune is literally moving, in whole, from one location to another. Meanwhile she has activated an alternative resource, that of sand moving a little bit at a time.

The second rejection of the deterministic explanation is subtle as she presents it as a conflict between what she expects to *make sense* and her intuitions about how wind blows sand.

"I keep thinking about a joke or a story, you know if a bird comes and takes one grain of sand and then dumps it and one grain of sand and dumps it, then like, if you keep dumping them on top of each other it would be like, you know, when you dump whole bunch of sand and it makes like a cone shape. That would make sense. But, I don't know how the wind, cause the wind doesn't work like that linearly."

This explanation addresses how the wind could move sand dunes sequentially. While this explanation does contain a deterministic mechanism, that of a bird moving individual grains of sand, it is focused on the movement of sand at the particle level; unlike the prior explanation which focused on the movement of an entire dune. In this case, she admits that the explanation makes sense, but rejects the idea because the wind does not work linearly, like a trained bird. Simultaneously she has activated a resource, that of the sand particles accumulating on top of each other. The accumulation resource and the sand moving a little bit at a time resource both proved relevant to subsequent explanations.

Mid-level 'Layers' Explanation

The second explanation focused at the mid-level layers, that of sand moving in stages, a layer at a time. This explanation arose as she rejected the deterministic explanation, and at the same time activated new resources, that of wind not working in a constant manner, sand moving in a stage process a little bit at a time, and sand accumulating into a dune. These additional resources were then used as a central idea in the mid-level layers.

“This top layer of sand would kind of get blown first... But some of the outside of the sand dune [motions for the outside of a dune] 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, some of the outside again, and those ones would get blown over here somehow and then it would start, I don't know. Then it would keep doing that until it all kind of moved over here, to a new sand dune. But then, I know that when its windy, its 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.”

In this explanation Laurel has explained that layers of sand move sequentially, but she then rejects this explanation because she views the wind as not being constant. This explanation operates at the intermediate grain-size level, different from the previously discussed deterministic explanations. Laurel is not paying attention to the movement of the entire dune at once, nor is she paying attention to only the movement of individual sand particles, she is instead paying attention to the movement of collections of sand particles such as the “top layer of sand.” This explanation uses “mid-level” strategy that Levy and Wilensky [8] found to be pervasive among middle school students; they found that this strategy may support students reasoning about complex systems as it reduces the amount of information needed to reason about the system. The mid-level layer explanation may have been productive for Laurel; it provided a viable alternative to the deterministic explanations as it was able to account for the movement of sand dunes at an intermediate level between the bird story and the whole dune movement explanation. The rejection of the mid-level layers explanation, due to the non-constant wind, then becomes a foundation for the next explanation. Once Laurel concluded that the wind was not constant, she considers a new mechanism for the movement of sand dunes, the sand stacking mechanism.

Sand Stacking Explanation

After rejecting several different explanations (the mid-level layers explanation and the deterministic explanation) Laurel then uses the idea of wind not being constant to build a new explanation for how particles of sand move, the particles stack together. This explanation explores the compactness of sand, how and when the particles stack (or stick) together. “I guess, since the sand is like kind of loose [moves

hands outwards], its not like it's glued together or compacted or something [holds hands together].” In a second case, this idea is explored further to explain how dunes can increase and decrease in size. “Sand that was being blown would get stuck there, or not stuck, but like it would kind of, maybe hit the, it could hit the, hills somehow and stop there, right? It would kind of join in, in a way, with that little pile and then it would start get bigger and bigger.” In this case she first mentions that the sand would get stuck, but takes it back, she may have recognized that sand is both stuck and loose at the same time. The sand stacking idea is then used to explain how the dune would increase in size. This explanation operates at the level of individual particles of sand, but it is used to justify how entire dunes change size. Consequently, this explanation is taking a step towards the accurate emergence idea as the behavior of the individual particles of sand is used to explain the overall increase in size of sand dunes.

Emergent Behavior Explanation

Soon after the above episode the sand stacking idea is then incorporated into the general explanation for how dunes get smaller and bigger.

“I was saying how the wind was like taking the outside layer or something, maybe it's like this big and then it starts doing that and the dune gets smaller. But it wouldn't get flat probably, there would still be a little cone there and then maybe that would start collecting more and growing and then the wind could take it away get smaller and like this. Maybe it's more like a wave getting bigger and then getting smaller and then getting bigger. Just rotating like that...Maybe it depends on like, cause if things are being, like joining in and some things are being blown away, I'm thinking that if that's happening equally then its never going to change.”

This explanation contains the central emergence idea, that of the wind taking away sand, and the dune collecting sand in such a way that it is a cyclical pattern of the dune getting bigger and smaller depending on the rate of these processes. The implication of an oscillatory process would seem to be evident of a sophisticated way of thinking about the phenomena. Furthermore, Laurel is able to fluently move among different levels; in the above explanation she mentioned the mid-level layers, the changes to the overall dune, and the movement of individual particles of sand. It may be that one attribute of a sophisticated emergent explanations is the ability to fluently move between these different levels and consider different perspectives on the phenomena.

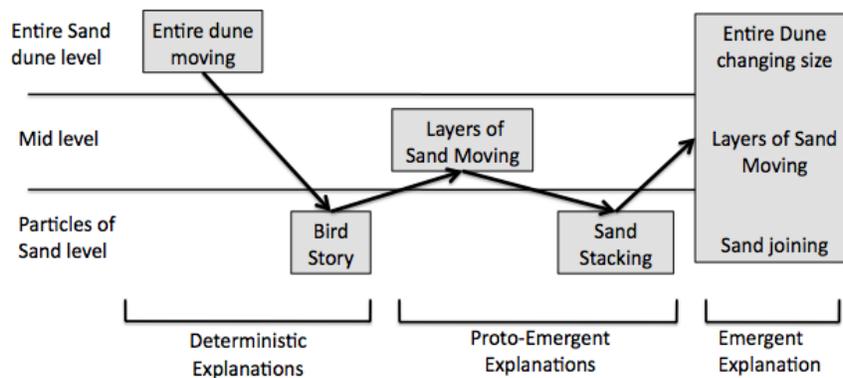


FIGURE 1. Schematization of the different levels that Laurel's explanation transverses during the interview.

DISCUSSION

In this paper I have presented a case study in which a cogent explanation about an emergent phenomena was constructed using the genuine emergent causality. To build this emergent explanation Laurel negotiated the flaws and benefits of four explanations. For Laurel the flaws in prior explanations, which were based on her particular knowledge resources, may have served as a way to move between different explanations at different points in time.

At different points in time her explanations involved different levels (see figure 1). The first deterministic explanation was focused on the movement of the entire sand dune. The second deterministic explanation was the story of a bird sequentially dropping individual grains of sand. The proto-emergent explanations included both the mid-level layers explanation which focused on outer layers of sand moving sequentially and the explanation about particles of sand stacking. The final explanation contained the emergent idea which was multi-leveled. I hypothesize that moving between these levels may have been productive for Laurel as her final cogent emergent explanation was concurrently multi-leveled. Possibly, the ability to fluently move among different levels is a characteristic of a sophisticated emergent explanation. This analysis is presented as one possible path that someone may take in order to construct an explanation for an emergent phenomena.

Despite the multiple ways of explaining this phenomena exhibited during the interview, she may not have necessarily had the emergent explanation at the beginning of the interview. At the beginning, the deterministic explanation made sense and she was tempted by it, but over time she recognized its flaws and used her resources to construct the genuinely emergent explanation. Likely the particular resources

she was able to access within different levels influenced the types of explanations she was able to generate; her ability to fluidly move among these levels contributed to the final emergent explanation. The trajectory of Laurel's explanations suggests that it is possible to generate genuinely emergent explanations with minimal scaffolding. Rather than assume that students always have or do not have a given type of explanation; we should instead focus on supporting students to use their resources to construct the appropriate explanation.

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