

Developing Conceptual Understanding Through the Use of Computer-Based Representations

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This research concerns the relation between specific features of a piece of technology and the development of conceptual understanding. Occasionally, people talk about technology as an effective tool for enhancing understanding and some other technologies that are less effective or even detrimental. Experimental findings can measure the effectiveness of such technological environments but they cannot provide the reason and the causality behind it. How do we know that the development of conceptual understanding is fostered by the technology and in what ways? How do specific features of the design relate to the desirable learning outcome? This work investigates how a specific design of computer-based representations (simulations) facilitates the development of conceptual understanding of complex phenomena. It aims to construct a model that describes mechanisms of developing understanding as facilitated by the use of computer-based representations. Such explanations at the level of mechanisms provide the means for understanding how and why specific aspects of design relate to a desired outcome in students' learning.

Theoretical background

Visual representations are prevalent in our culture. They are designed to boost our grasp of patterns and trends, to organize complex data, to manage information, to structure experience, to model various phenomena and so forth. This work strives to explain on the level of fine grained mechanisms, the role of specific features of designed representations in the development of conceptual understanding of physical phenomena. Specifically, I explore how a specific design of representations facilitates students' understanding of natural harmonic oscillation.

The process of developing understanding through the use of computer-based representations has hardly been explored at the level of fine-grained mechanisms, as this research attempts to do. There are at least two exceptions to this claim. One is a detailed microgenetic analysis that describes one student's knowledge structures as they changed and developed through learning with Cartesian graphs (Schoenfeld, Smith, & Arcavi, 1993). Sherin (2001) examines in detail the difference between two representational systems: a programming language and the algebraic symbol system for learning physics. He provides a sound theoretical and empirical basis for understanding how symbol use of particular symbol systems affects students' conceptualization. My research attempts to provide a similar kind of theoretical and empirical foundation to our understanding of how a specific type of representations facilitates peoples' conceptualization.

There is considerable research on representations and understanding that provides a reasonable basis from which to begin this exploration. Below are three claims that are considered the state-of-the-art of learning with representations. The three claims are generalization of more specific arguments made by different researchers that are concerned with issues of representations and cognition:

Claim 1: External representations can highlight theoretically important aspects of the phenomenon. (Norman, 1993; Zhang & Norman, 1994; Scaife & Rogers, 1996).

Claim 2: Interaction with multiple representations can promote deeper, abstract and general understanding. (Yerushalmy, 1991; Kaput, 1989; Ainsworth, 1999).

Claim 3: The interactivity and dynamic nature of computational representations support visualization and experimentation with aspects of the studied phenomenon. (Scaife & Rogers, 1996; Jones & Scaife, 2000; Narayanan & Hegarty, 2000).

These claims present a specific background on which I develop refinements as a result of my analysis. They are revisited through my analysis and are revised and refined to better and more completely account for the role of computer-based representations in the context of my studies.

Method

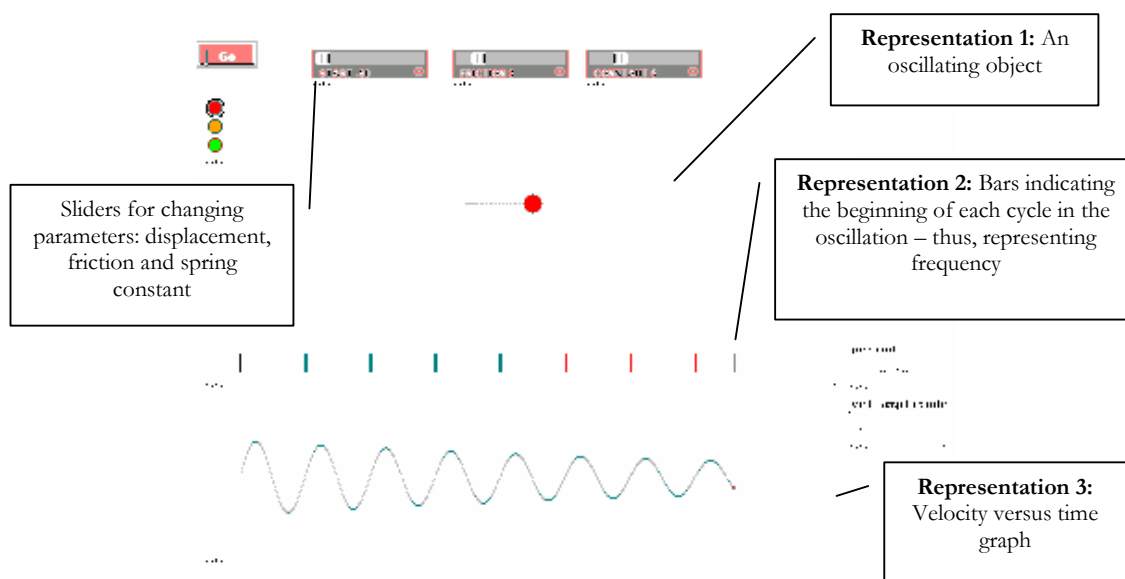
Data

The data comes from observations of eight pairs of students engaging in explorations of the phenomena of natural harmonic oscillation through the use of computational representations. The subjects are high school students ranging from 9th to 12th grades. In the first part of each session students explore the physical phenomenon using physical devices. In the second part, students work with computational representations exploring the same phenomenon. All sessions are videotaped, transcribed in detail and coded according to an evolving analytical framework.

The session

Oscillatory motion is key in learning physics as it appears in many forms and situations in nature (swings, pendulums, vibration in music instruments, earthquakes, etc.) and crosses many curricular domains in physics (mechanics, electricity, magnetism, etc.).

In the sessions I conducted, students interacted with both physical oscillators and with a simulation. The students were engaged with questions such as: what does fast mean? What exactly slows down in a damped oscillation? What happens to the period in a damped oscillation? Etc. The simulation includes three linked representations: (1) An animation of an oscillating object that goes back and forth and leaves traces behind; (2) “The bar representation” is produced by the depiction of one bar on a time line, every time the oscillating object begins a new cycle – hence representing the periods and the frequency of the oscillator, and (3) A velocity versus time graph. Students can change the amount of displacement, the friction and the spring constant of the oscillator, and thus explore some of the causality in oscillatory motion.



Analytical methods

The research aims to develop a model that describes mechanisms of developing understanding as mediated by the use of representations. I maintained that a close examination of the process of development can shed light on how changes in conceptual understanding happen and how representations play a role in this process. In order to develop such a model, the analysis is based on coordination class theory (diSessa & Sherin, 1998; diSessa, 2002) and combines aspects from three methodological approaches: knowledge analysis (diSessa, 1993), grounded theory (Glaser & Strauss, 1967), and microgenetic analysis (Siegler & Crowley, 1991; Schoenfeld, Arcavi, & Smith, 1993).

Findings and discussion

The analysis traces the moment-by-moment development in students' conceptual understanding through their interaction with the simulation. In their interaction with the physical oscillators, prior to the work with the simulation, most students demonstrated several conceptual difficulties:

- Students used the term "fast" to denote many types of "fastness" including: instantaneous velocity, frequency, average linear velocity, peak velocity, acceleration and more. In most cases, students were not able to differentiate these various concepts which resulted many times in conflicting inferences and in a lot of confusion. In particular, students confused velocity and frequency which are key to understanding oscillatory motion.
- Students had difficulties separating out the various parameters of oscillation (Inhelder & Piaget, 1958).
- Students had difficulties to see the variation of velocity in oscillation. Many students simply believed that the speed within the cycle of an oscillation is constant, and they did not see the

variation: they did not grasp the change in velocity, they could not see the instantaneous stop when the oscillator changes direction, they were not convinced that changing direction implies changing signs, and therefore slowing down and stopping, and so forth.

For example, this is a short excerpt that demonstrates a common conversation organized around the exploration of physical oscillators:

Robin: This one (the pendulum) looks like it's going faster than the slinky...



Sue: Yeah, it does

OP: So, what do you mean by faster there?

Sue: It travels...

Robin: It's traveling in a higher velocity

Sue: Like, ah... velocity has...

Robin: Velocity actually has a direction or something

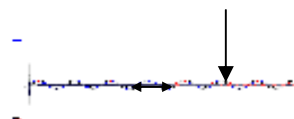
Sue: Higher rate

Robin: Higher rate, whatever

Part of the difficulty stems from their inability to get information in a reliable way about variables that participate in oscillatory motion.

Most students began resolving these difficulties through the interaction with the simulation. For example, the students whose excerpt is given above began to explore the simulation by observing the effect of changing the amount of displacement on the motion of the oscillator:

Robin: So, these are (points to the graph) at the same skinniness level but they are not as high, [Sue: yeah] like remember when it was fast [Sue: yeah] these things were really high...



Robin: But these are the same; I think these are the same... I think... (Points to the bars) [Sue: Are they?] Robin: [Yeah, see?]



(Robin changes the displacement back again to the right end and re-runs the simulation)

Robin: Now these look closer together. [Sue: no, no...] No, these look like the same... Those are the same but these are higher.

The properties of the representations play a major role in this process. They now have clear and stable perceptual foci that allow them to detect the patterns in the simulation: the “skinniness” of the graph (or the distance between the bars) and the height of the graph. These representational aspects are easy to point to, look at and compare. They can effortlessly infer that **“those are the same but these are higher.”** The two different patterns of variation (those are the same but these are higher) create a conceptual challenge on the background of an undifferentiated conceptualization, and they try to confront it:

Sue: So, like, (gestures to the screen to the oscillating ball) it's moving faster, it's...

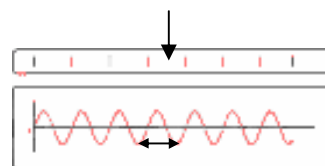


Robin: But the periods are the same, that's...



Sue: Yeah, [Robin: periods] but, in, [Robin: but it's going farther] it's going farther in the same amount of time

Robin: So there's more motion in the same amount of time.



Their undifferentiated conceptualization of “fastness” creates a conceptual challenge. Why are the distances between the bars the same while the oscillator **“is moving faster”**? As happens often when students face conceptual challenges, they are driven to search for meanings of the various aspects of the representations. They map the two independent representational aspects, the distance between bars and the height of the graph, onto two scientific concepts—“linear speed” and periods. As soon as they realize that in this particular situation the distances are also different: **“it’s going farther,”** they immediately resolve the conceptual challenge. With three motion variables: distance, time, and velocity they realize that velocity and distance can compensate so that the time stays the same.

This is one example of change in students’ understanding of the difference between frequency and velocity and the relation between them in the context of oscillatory motion. Based on the various processes of change observed in the eight sessions, a model was constructed that describes four mechanisms that drive the process of development of conceptual understanding:

- The pattern detection mechanism: Detecting patterns of variation of a specific representational aspect
- The challenging mechanism: Identifying a conceptual challenge
- The anchoring mechanism: Stabilizing of perceptual focus in the physical phenomenon
- The imprinting mechanism: Relating new conceptual elements to the existing knowledge system

The processes of development observed in my studies were driven by these four mechanisms that are supported in some ways by the properties of the representations. However, these cognitive mechanisms are not executed simply by responding to properties of the representations in any simple way. Rather, they are contingent on students’ conceptual resources as elaborated elsewhere (Parnafes, in review). Still, the studies provide strong evidence that most of the development happened when the students interacted with the simulation. What was the role of the computer-based representations in this process of development? The refinements of the three state-of-the-art claims based on the findings from the analysis provide answers to this question, and give rise to several design principles:

1. Representations bring theoretically important aspects of the phenomenon into focus, by providing alternative stable access to them. A possible design principle: simplifying the perceptual field by highlighting particular dimensions of the phenomenon that are theoretically important, may facilitate the stabilization of perception on those aspects. Another stabilization means is the transformation of temporal events into spatial relations.
2. Multiple representations make conceptual inconsistencies explicit that drive the seeking of conceptual coherence.
3. The interactive nature of computational representation supports systematic experimentation with aspects of studied phenomenon. Such experimentation enables the students to explore the causal relations between various aspects of the phenomenon.
4. The dynamic nature supports the mapping between representational aspects and correspondent aspects in the physical phenomenon. It is important that one of the representations, in this case, the

oscillating object, is a realistic one. If the phenomenon itself is dynamic (such as in the case of oscillation), a realistic representation should be dynamic too. A realistic representation could facilitate the mapping between the other representations and the physical phenomenon, and by that create the conditions for the anchoring mechanism.

Conclusions

This work seeks to contribute to the field's understanding of learning process with representations, by constructing a model of students' developing conceptual understanding as mediated by the use of representations. In addition to the theoretical contribution, this work can also inform the design of novel computational representations for learning.

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