Depictive Gestures as Evidence for Dynamic Mental Imagery in Four Types of Student Reasoning

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Abstract. We discuss evidence for the use of runnable imagery (imagistic simulation) in four types of student reasoning. In an in-depth case study of a high school physics class, we identified multiple instances of students running mental models, using analogies, using extreme cases, and using Gedanken experiments. Previous case studies of expert scientists have indicated that these processes can be central during scientific model construction; here we discuss their spontaneous use by students. We also discuss their association with spontaneous, depictive gestures, which we interpret as an indicator of the use of dynamic and kinesthetic imagery. Of the numerous instances of these forms of reasoning observed in the class, most were associated with depictive gestures and over half with gestures that depicted motion or force. This evidence suggests that runnable, dynamic mental imagery can be very important in student reasoning.

Keywords: Models; modeling; analogies; imagery; pedagogy; imagistic simulation.
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INTRODUCTION

Previous case studies of expert scientists have indicated that running mental models, using extreme cases, using analogies, and using Gedanken experiments can be central reasoning processes in scientific model construction [1-3]. It has been argued that the ability to generate and evaluate mental models is a crucial aspect of science [4, 5], and that students need to be helped to assimilate prior experience into accepted models [6]. Research continues to indicate the importance of mental modeling in experts and students [7, 8]. We believe there is much more that can be learned about the variety of reasoning processes students employ in the classroom to evaluate mental models.

METHODOLOGY

In the present paper, we report on a transcript of classroom activity where inquiry-based methods of teaching and learning were employed. As part of a larger project, we have already coded a number of transcripts of classroom activity for imagery indicators [9, 10]. We coded additional transcripts for the presence of depictive hand motions, only. These hand motions appear to depict an image in the air, and are taken as one indication that mental imagery is being used [11]. Here, we analyze one particular class for the presence of the four expert reasoning processes and for their co-occurrence with depictive hand motions, which will be the main form of imagery indicator considered in this paper. We are still using the coding process as a way to refine definitions of categories for these processes, so in all cases, coding for processes was done jointly by the two authors and disputes were used as a mechanism for refining and clarifying the coding criteria. The four thinking processes—running an explanatory model, using extreme cases, using analogies, and using evaluative Gedanken experiments—as defined here, are not intended as mutually exclusive categories. In some circumstances, more than one can apply to the same case.

We cannot present the full case study here, but merely attempt to illustrate a methodology for identifying types of student reasoning and examining whether they depend on mental simulations run via the use of dynamic imagery (*imagistic simulations*). We will define each process, describe an example of each, and discuss our coding for gesture in each example. We will also review the results of coding the whole transcript, which, in this case, showed a strong correlation between the four thought processes and depictive gestures.

In the examples below, the gestures are coded as Shape Indicating [G-S], Movement Indicating [G-M], or Force Indicating [G-F], according to the images they appeared to depict. We refer to the Movement

Indicating and Force Indicating gestures collectively as *Action* gestures. Students' use of movement or force terms in conjunction with their gestures was considered added evidence that could strengthen our choice of coding, and we note such terms in boldface. (See the list of imagery indicators in [11].)

EXAMPLES OF FOUR EXPERT REASONING PROCESSES

This case study is of a lengthy discussion that occurred in a college preparatory physics class that was using an innovative curriculum [12]. The class was in a middle-class suburban high school in the northeastern United States. The discussion, which was videotaped, lasted about 45 minutes.

The teacher wanted students to consider whether a table exerts an upward force on objects resting on its surface. A common conception prior to instruction is that inanimate objects cannot exert upward forces against gravity. The target model for the lesson was one in which objects exert normal forces that are equal and opposite to the weight of objects resting on them. The teacher began by introducing an analogy. He placed a book on his desk and called students' attention to it, then drew two figures on the chalkboard. One was a simple line drawing of a book on a table (the target), and another of a hand pressing downward on a spring (the base). He hoped that all of the students would believe that the spring pushed up on the hand and that he could use this as an anchoring case for the lesson. It became clear that, although many of the students did believe that the spring would exert a force on the hand, a large number did not believe that the table was exerting an upward force on the book. The teacher intended to introduce a number of *bridging analogies* [13], designed to bridge the distance between the spring/hand case and the table/book case. However, these students preempted him, producing their own bridging cases and reasoning about them.

A minute or so into the discussion, S4 agreed that a spring could exert a force back against a hand, but argued that the table is not equivalent:

> S4: . . . and if you kind of release the spring, it would force your hand up, where the table's not going to push the book up.
>
> T: I see . . . there's no way we could use the table to uh, send things flying off into outer space now, the way a spring might. Hmm.

The four examples that follow occasionally refer back to this exchange, although they all occurred somewhat later in the discussion.

Running an Explanatory Model

An explanatory model is defined here as a mental model of a system that projects some initially hidden feature into the system and that offers an explanation for why it behaves the way it does.

> S13: If you put something heavy on the table and it collapsed, that is because the table is not exerting enough force. If you put something on the table that was like, really [G-F] heavy, and the table [G-M] **collapsed**, I would argue that that was because the table is not exerting enough force on whatever is on top of it.

Saying "if you put something heavy on a table it will collapse" can be interpreted as running a mental model of a table, although this model is not yet explanatory. The model predicts that the table will collapse under certain conditions, those conditions being when it is subjected to a weight great enough. However, to go on to reason that the *cause* of this behavior is that the table does not exert enough force to hold up the weight is to project the initially hidden feature of forces into the table, producing an *explanatory model* of this system.

The gestures suggest the presence of mental imagery that has both visual and kinesthetic components. Even though the student did not specify what was being put on the table, he appeared to be reacting to the weight of something "really heavy." He also appeared to depict the motion of the table as it collapsed.

Extreme Cases

We say that an extreme case has been run when a subject, in thinking about a target situation A, shifts, without being prompted, to consider situation E (the extreme case) where some variable from situation A has been maximized or minimized.

Early in the discussion, when arguing that the table *does* exert a force, S15 had proposed that the table warps slightly and pushes back against the object. Now, over half an hour later, S5 returned to that point to argue that the table does not have enough power to "exceed" the weight of an object to move it in the other direction, "and as soon as (*the weight*) gets too great then the table collapses." S15 then recast this statement as an extreme case of warping in order to argue *for* the normal force:

> S15: (*S5's*) idea is compatible with the warped table theory. The idea is that the [G-S] elephant sitting on the table is too much [G-S] for the material that the table is made out of, and it [G-F] **punctures** the thing; it [G-S] warps it too much.

The shape depicted by the final gesture was a deep upward curve, much deeper than a table could normally form without breaking. By pushing the warped table to an extreme, the student had transformed the first case into the second. Numerous gestures give indication of the presence of visual imagery, and the force gesture accompanied by the force term *punctures* suggests the presence of kinesthetic imagery.

Analogies

For our purposes, analogies occur when a subject, in thinking about a situation A (the target), shifts, without being prompted, to consider a situation B (the base) which differs in some significant way from A, and intends to apply findings from B to A.

About a half hour into the discussion, a student made an analogy between two cancellations: the cancellation of *velocities* between a powerboat and a current (which would cause the boat to remain still with respect to the shore) and the cancellation of *forces* between gravity and the normal force (which would cause the book to remain at rest on the table). The student reasoned about what would happen to the boat if the current were taken away, and by analogy, what would happen to the book if the force of the table were taken away. (Although the analogy would have been stronger had the student said—or meant—*forces* from the current and the boat's engine, taking his words at face value still indicates the use of an analogy; a vector representation of the cancellation of velocities and the cancellation of forces is visually equivalent.) In the student's words:

> S14: The book is pushing down, say with, um, it's a little far fetched, but (*pause*) with the velocity of the engine, it's **pushing** [G-F] down. And the table's pushing up with the velocity of the current. If you take the current away, then the engine (*unintelligible*), if you take the [G-F] **force** of the table away, then the book would just fall [G-M] down.

The use of the force term *pushing* reinforces the impression that the student was indicating a force with his gesture even though he had just referred to the "velocity of the engine." The student's gestures created a stronger parallel between the two situations than did his words, as he reasoned about a scenario that was proving confusing to many of his classmates.

Evaluative Gedanken Experiments

An evaluative Gedanken experiment is defined here as the act of considering an untested, observable system designed to help evaluate a scientific concept, model, or theory—and attempting to predict aspects of its behavior. In these experiments, an element of a theory is tested as it is applied to the untested system. These experiments, as discussed in [2], can be quite complex, come in many varieties, and can incorporate the other three types of reasoning.

In this example, which occurred immediately after the analogy example above, S15 used the same analogy. Rather than taking the current (normal force) away, however, he imagined taking the engine (force of gravity) away, and predicted what would happen to the boat (book):

> S15: But by the same analogy, then, if gravity disappeared, right, the **force** of the [G-F, *sudden thrust downward*] engine on the book, even the book would just [G-M, *flings arms upward and outward*] **fly** off into space.

If the engine disappeared, the current would move the boat, and by analogy, if gravity disappeared, the normal force would send the book off into space. (The table would suddenly unwarp.) The case of gravity disappearing is an untested system and the student attempted to predict an aspect of its behavior—what would happen to a book on a table in such a situation. The case appears to have been constructed to evaluate an aspect of the theory of normal forces.

For this example, we have included descriptions of the gestures, as we have not, for reasons of space, done elsewhere. The descriptions are intended to convey to the reader the energetic quality of these gestures, which we take to be indications of the student's use of imagery that had kinesthetic, as well as visual, components.

FINDINGS

In the 45 minutes of transcript, we coded (with each category including the one below it):

- 22 instances of the four expert reasoning processes, where
- 17 of the 22 instances were paired with depictive gestures;
- 12 of these 17 instances involved depictive gestures that were action gestures (indicating force or motion), and
- 5 of these 12 instances involved, specifically, force-indicating gestures.

In addition to the 17 instances where expert reasoning processes were paired with depictive gestures, 7 other utterances co-occurred with depictive gestures, leading to a total of 24 utterances co-occurring with depictive gestures, as shown in Table 1. Many of these utterances were accompanied by multiple gestures; we coded 53 individual depictive gestures made by the students.

TABLE 1. Utterances Co-Occurring with Depictive Gestures

Expert reasoning processes paired with depictive gestures	17
Other utterances paired with depictive gestures	7
Total utterances paired with depictive gestures	24

An example of the coding is given in Table 2. The transcript line numbers hint at the density of these reasoning processes in this classroom discussion. Note the occurrence of action gestures with most, if not all, of these incidents. (The partially obscured gesture was not included in the totals.)

In summary, most instances of these reasoning processes were associated with depictive gestures and over half with gestures that depicted motion or force. This case study provides evidence indicating that runnable mental imagery (imagistic simulation) can be closely associated with, and may be centrally important in, four types of student reasoning with mental models. This supports the importance of fostering the development of effective, runnable mental models as a goal in science pedagogy and underlines the possible value of gestures as a window onto student imagery. Our long-range hypothesis is that runnable mental models engender a form of sense making in science that contrasts sharply with a knowledge of memorized facts or rules.

TABLE 2. Coding Summary for One Section of Transcript

	Line 98	*Line 105*	*Line 112*	*Line 114*	*Line 122*	*Line 125*
Reasoning Processes	Gedanken Exp. Extreme Case	Running Model	Analogy	Gedanken Exp. Running Model	Running Model	Extreme Case
Gestures	[G-S] 2 [G-M] 4	[G-M] 1? (ptly obscured)	[G-M] 1 [G-F] 2	[G-M] 1 [G-F] 1	[G-M] 1 [G-F] 1	[G-M] 4

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